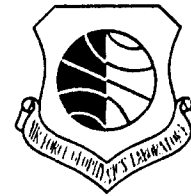


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**Airborne Measurement of Aerosol Size
Distributions Over Northern Europe**
Volume I. Spring and Fall 1976, Summer 1977

TED S. CRESS, Lt Col, USAF

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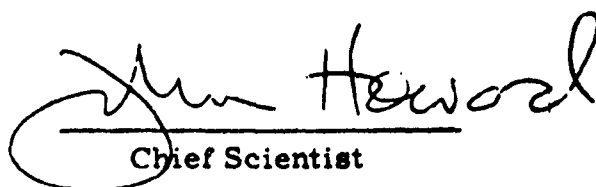
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20. Abstract (Continued)

earlier over the midwestern U.S. using an impactor. Sampling analysis, and comparison to nephelometer measurements, indicate the aerosol measurements probably always represent the dry aerosol particle distribution vice the actual distribution (in balance with existing relative humidity) sensed by the nephelometer. These data provide an excellent picture of the relative changes that were found to occur in the vertical, and in space and time, with changing synoptic conditions.

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Preface

This report describes one aspect of an aircraft measurement program which was conducted to support a ground measurement program conceived, planned and implemented by several NATO countries represented in one of the Research Study Groups of the NATO Defense Research Group.

This volume, Volume 1, presents aerosol distribution data obtained in the first three deployments of a five deployment series. Also presented is a cursory analysis of the most obvious characteristics of the data base and a comparison to previously obtained data.

The second volume of this report will contain the data obtained during the last two deployments, a data base exceeding that being presented here by almost a factor of two.

In these reports, data from several sources are being utilized to present a complete synoptic picture. Daily synoptic weather maps, surface and 500 mb, presented were prepared by the FRG Weather Service and the Deutscher Witterdienst and were presented in daily Wetterkarte des Deutscher Witterdienst. These maps are used only for a visual depiction of the synoptic pattern, but not for any quantitative evaluations. Likewise, the vertical profiles of scattering coefficient were prepared by the Visibility Laboratory, Scripps Institute of Oceanography, University of California, San Diego and are presented in this report to give context to the individual aerosol measurements.

During the deployment of the AFGL optical physics C-130 aircraft to Europe, the aircraft typically staged out of non-U.S. airbases near the data sites. Without the outstanding cooperation of host base personnel (upon whom we were undoubtedly

a burden), officials of the national defense organizations, officials of the National Air Traffic Control Agencies, and members of the NATO Research Group, this measurement program could not have been successfully completed. Our thanks and a debt of gratitude go out to all who helped this effort succeed. I do not feel it is out of place to say that these individuals welcomed us and made us feel welcome—it was a pleasant and gratifying experience.

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Airborne Measurement of Aerosol Size Distributions Over Northern Europe

Volume I. Spring and Fall 1976, Summer 1977

1. INTRODUCTION

This report presents and discusses aerosol concentrations and size distributions measured at a variety of altitudes and locations over Europe between 1976 and 1978 as part of the United States contribution to the cooperative NATO OPAQUE project. OPAQUE (acronym for Optical Atmospheric Quantities in Europe), a two- to three-year effort by eight NATO countries, as members of Research Study Group-8 (h2G-8), Panel IV, AC-243, NATO Defense Research Group, was developed to document atmospheric electro-optical transmission properties in western and central Europe. OPAQUE participants included Canada, Denmark, the Federal Republic of Germany, France, Italy, the Netherlands, the United Kingdom, and the United States. Seven ground station sites were identified within the European area, as representative sites for routine measurements of the optical environment. Routine measurements were to include illuminance, extinction, IR transmission, path luminance, spectral solar transmission, optical turbulence, and meteorological parameters. Later, measurements of aerosol size distribution and concentration were included for routine measurement.

As part of the U.S. effort for OPAQUE, in addition to the US/FRG cooperative ground station at Meppen, Germany (Fenn¹ and Fenn, et al²), AFGL opted to

(Received for publication 29 May 1980)

The references cited above will not be listed here, see References, page 123.

use its optically instrumented C-130A aircraft to obtain data in the vertical over each OPAQUE ground station, in each season of the year. Aerosol measurements were included as part of the aircraft optical data acquisition system. Initially, plans called for the C-130A to deploy to Europe in a Series of four 2-month deployments, spending 7 to 14 days flying over each location. A fifth deployment was planned if required. The first three deployments were carried out in spring 1976, winter 1976-1977, and summer 1977. This report, Volume I, presents the aerosol data from those three deployments, with the data from the remaining two to be presented in a subsequent volume.

This report makes available the aircraft-measured aerosol distribution in a logical and meaningful manner. Since these measurements are, for statistical analysis purposes, independent and essentially unrelated, they are presented as a series of individual case studies and should only be used in that manner. Nonetheless, these data serve to clarify the vertical structure of aerosol size distribution and concentration and to more clearly define the probable differences and similarities in the vertical between different air mass and stability regimes. These data should be highly valuable to the evaluation of potential aerosol models, but are only of limited value to statistical characterizations of aerosol distributions at a given time or location.

2. OPERATIONS SUMMARY

2.1 Site Locations

After extensive deliberation by the eight participating countries represented on RSG-8, seven sites were selected as necessary to adequately represent the major varieties of the European environment. These sites, chosen from many possible, were selected on the basis of logistics, economics, major climatic representativeness, anthropogenic influences, and applicability of data to NATO interests (Fenn¹). These seven sites and pertinent descriptive data are listed in Table 1. Figure 1 shows site and flight track locations on the European continent.

2.2 Flight Tracks

The flight tracks for the C-130, in many cases, could not be coordinated with air traffic control agencies to be directly over the ground OPAQUE sites. Most tracks were finalized within several kilometers of each site but in several cases (for example, the Christchurch and Ypenburg sites) it was necessary to position the flight track at some distance from the OPAQUE sites. Still it was felt that this displacement should not seriously change the validity of the vertical structure, but may, indeed, affect the representativeness of the correlation of the low

Table 1. OPAQUE Ground Sites

Site	Country of Location	Site Operating Agency(s)	Site Coordinates	Major Optical Environment	Comments
Meppen	FRG	US/AFGL, FRG/German Army Proving Ground 91	52°52'N 7°23'E	Rural North German Plain	Additional 20 C-130 data flights, May-June 1973 (Duntley ³)
Birkhof	FRG	FRG/Forschungsinstitut für Optik, Tübingen	48°14'N 9°11'E	Rural Low Alpine Plateau	13 C-130 data flights over Donau Valley to East, May-June 1970 (Duntley ⁴)
Rodby	Denmark	DK/Danish Defence Research Establishment CA/Defense Research Establishment	54°37'N 11°28'E	Northern Maritime	10 km SE of Rodby on Southeast Coast of Lolland Island
Ypenburg	Netherlands	NL/Physics Laboratory TNO	52°03'N 4°22'E	Urban Industrial	Near Coast
Bruz	France	FR/Centre d'Electronique de l'Armement	47°59'N 1°43'W	Rural Modified Maritime	18 km South of Rennes
Christchurch	United Kingdom	UK/Royal Signals Research Establishment	50°47'N 1°47'W	Modified Maritime	
Trapani	Italy	IT/Consiglio Tecnico Scientifico della Difesa	37°55'N 12°29'E	Mediterranean Maritime	Operational 1 Dec 78

3. Duntley, S. Q., Johnson, R. W., and Gordon, J. I. (1976) Airborne Measurements of Optical Atmospheric Properties in Northern Germany, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 76-17, AFCRL-TR-76-0188, AD A035 571.

4. Duntley, S. Q., Johnson, R. W., and Gordon, J. I. (1972) Airborne Measurements of Optical Atmospheric Properties in Southern Germany, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 72-64, AFCRL-72-0255, AD 747 490.

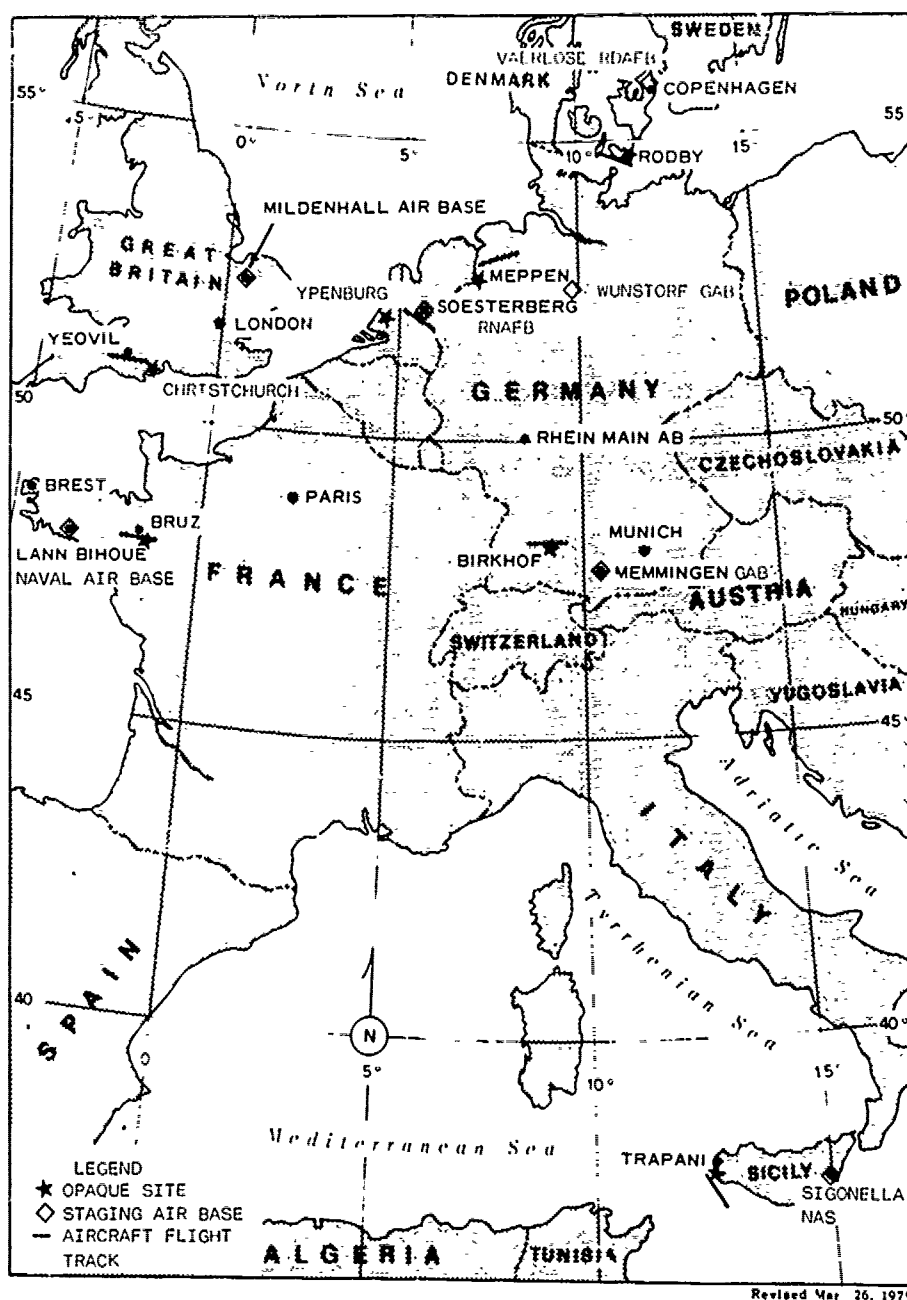


Figure 1. OPAQUE Ground Station Sites and Aircraft Flight Tracks

altitude data to the simultaneous ground site data. The individual tracks are shown in Figures 2 through 8 with detailed information in Table 2.

The standard flight profile for the C-130, Figure 9, was a series of straight and level (SL) sequences and vertical profile (V-PRO) ascents and descents. The profile was designed to permit acquisition of pertinent optical data in two different filters. The complete profile began with an SL sequence with a minimum altitude of about 300 meters above ground and continued, ideally, with alternating climbs to 1500 m, 3000 m, and 4000 to 6000 m MSL (above mean sea level). The V-PRO sequences were used to obtain continuous nephelometer measurements in the vertical, providing information on the vertical structuring of the aerosol distribution. For aerosol data, each SL leg, ten minutes long (or 50 km), was used to obtain aerosol measurements in one-, four-, or ten-minute sampling increments. As the full profile was flown only in fair weather, all aerosol data are from clear air away from clouds. No data were taken within fogs or clouds, nor could have the installed aerosol counter provided reliable data in such cases, as will be discussed.

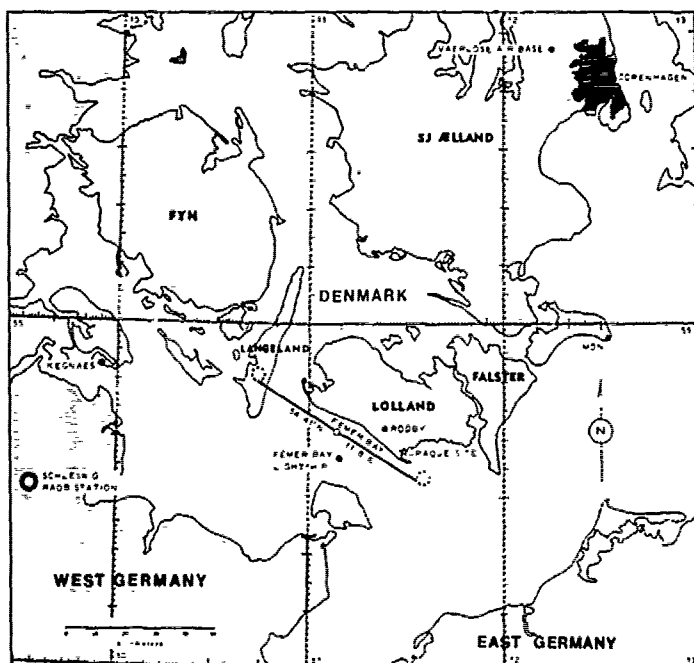


Figure 2. Flight Track Area Near Danish Ground Site
(Courtesy of Visibility Laboratory, University of
California, San Diego)

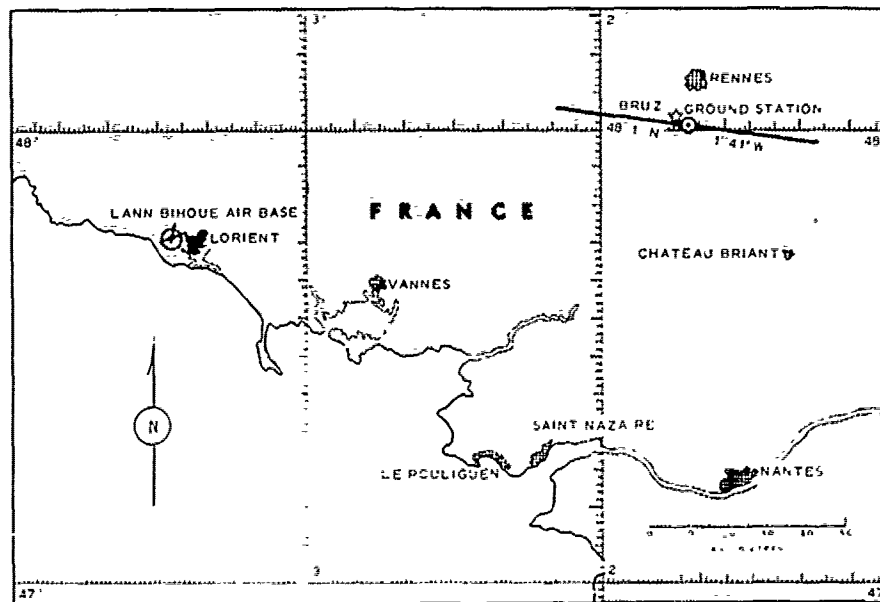


Figure 3. Flight Track Area Near French Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

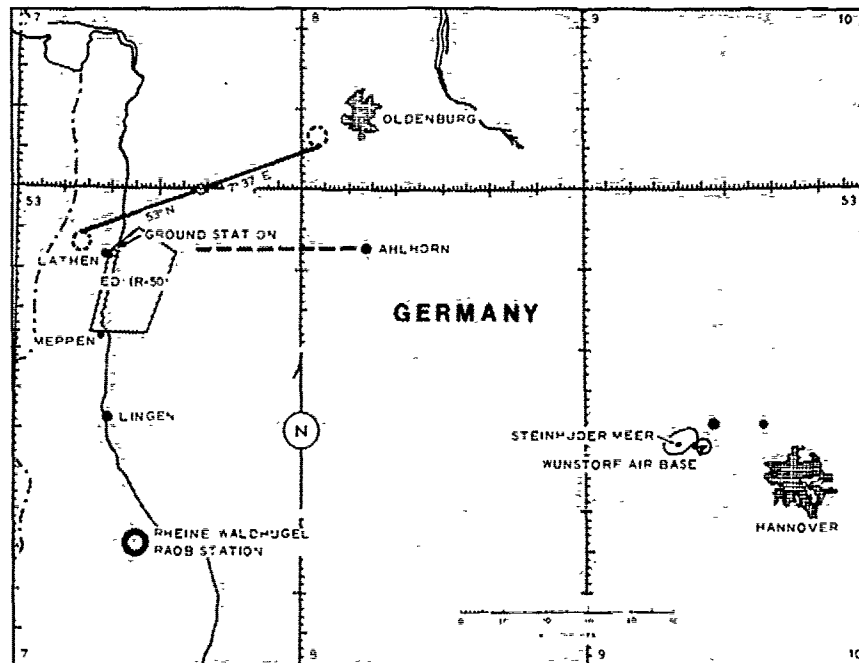


Figure 4. Flight Track Area Near Northern Germany Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

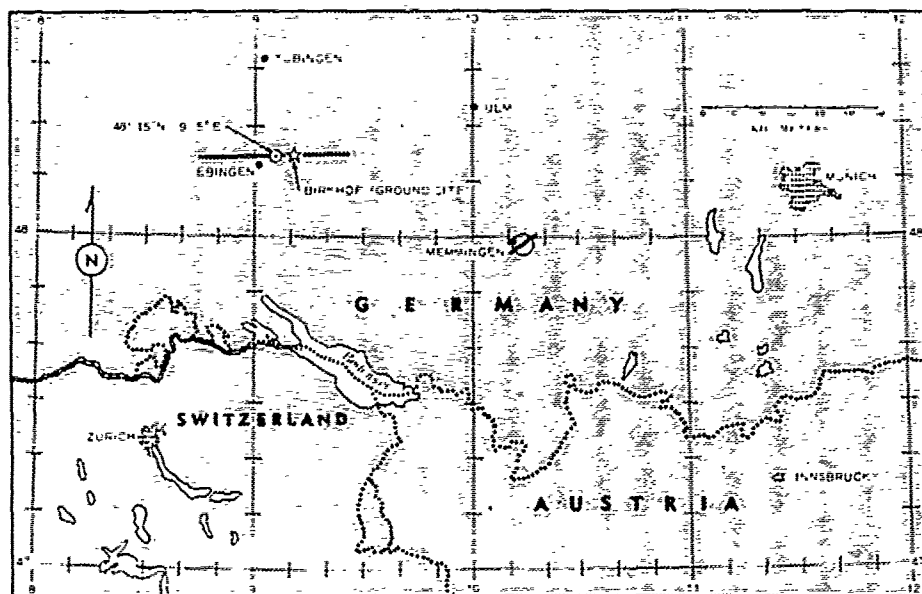


Figure 5. Flight Track Area Near Southern Germany Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

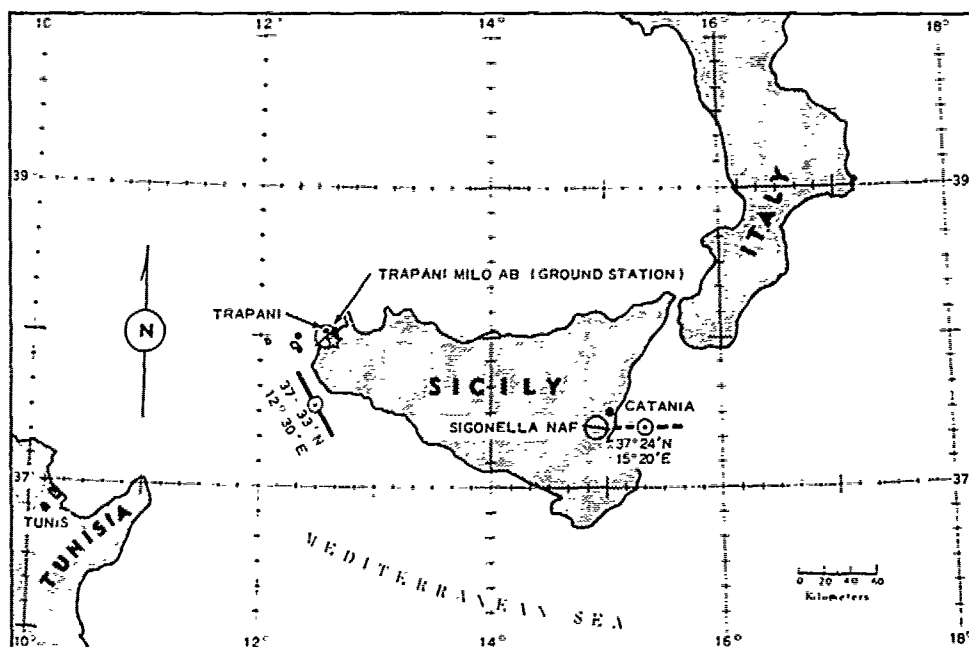


Figure 6. Flight Track Area Near Italian Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

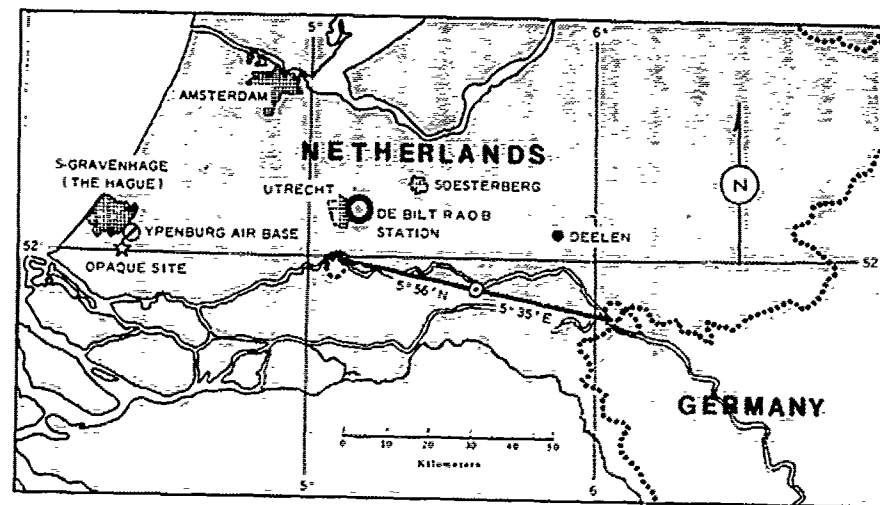


Figure 7. Flight Track Area Near Netherlands Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

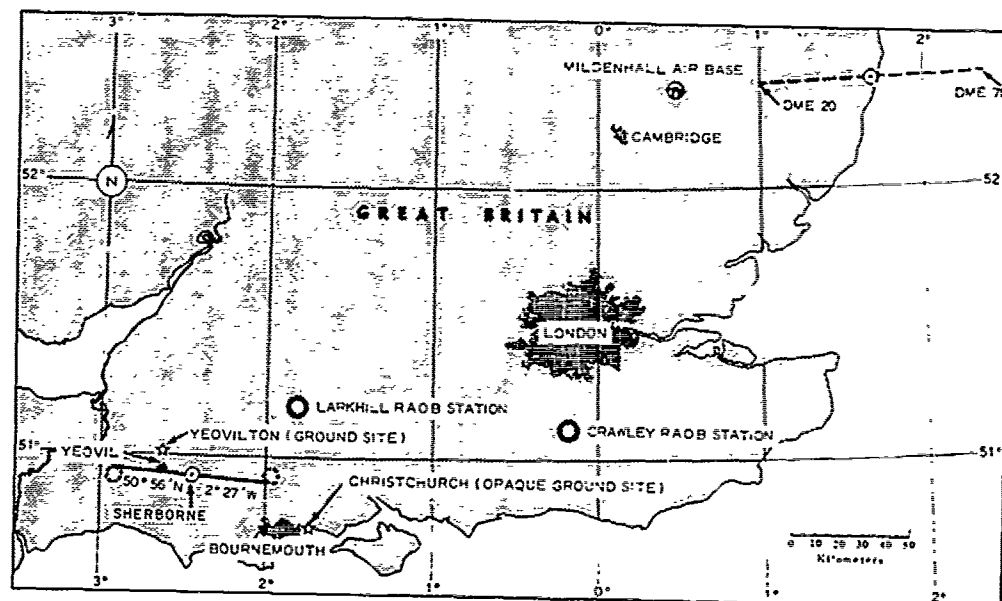


Figure 8. Flight Track Area Near United Kingdom Ground Site (Courtesy of Visibility Laboratory, University of California, San Diego)

Table 2. OPAQUE C-130 Flight Tracks

Site	Track Name	Western End Point	Eastern End Point	Operating Base(s)	Terrain	Avg. Elev. (m)	Elev. Range (m)	Comments
Meppen	Meppen	52°43'N 7°13'E	53°03'N 7°56'E	Wunstorf AB, FRG	Cultivated flat land	18	±10	Track to north and east of site due to NL border and restricted area.
Birrkhof	Birrkhof	48°15'N 8°45'E	48°15'N 9°26'E	Memmingen AB, FRG	Hilly plateau, river valleys at each end.	745	±200	Track is 5 km north of site due to restricted area.
Rodby	Rodby	54°51'N 10°43'E	54°35'N 11°25'E	Vaerlose AS, DK Wunstorf AB, FRG	Water	9	0	Track kept over water for homogeneity.
Ypenburg	Soesterberg	52°01'N 5°06'E	51°54'N 5°56'E	Soesterberg AB, NL Wunstorf AB, FRG RAF Mildenhall, UK	Cultivated flat land, many canals.	6	±4	Track over site not possible due to airspace restrictions.
Bruz	Bruz	48°03'N 2°09'W	47°58'N 1°16'W	Lann Bihoué NAS Lorient, FR	Cultivated rolling terrain with hills on west end and to south.	70	±30	
Christchurch	Sherborne	50°55'N 2°47'W	50°54'N 2°60'W	RAF Mildenhall, UK	Rolling hills.	60	±40	Track to north and west of site to avoid landing patterns of airfields near coast.
Trapani	Trapani	37°45'N 12°18'E	37°19'N 12°44'E	Sigonella NAS, Sicily	Water	0	0	Track to south of site over water for homogeneity and to avoid airfield traffic.

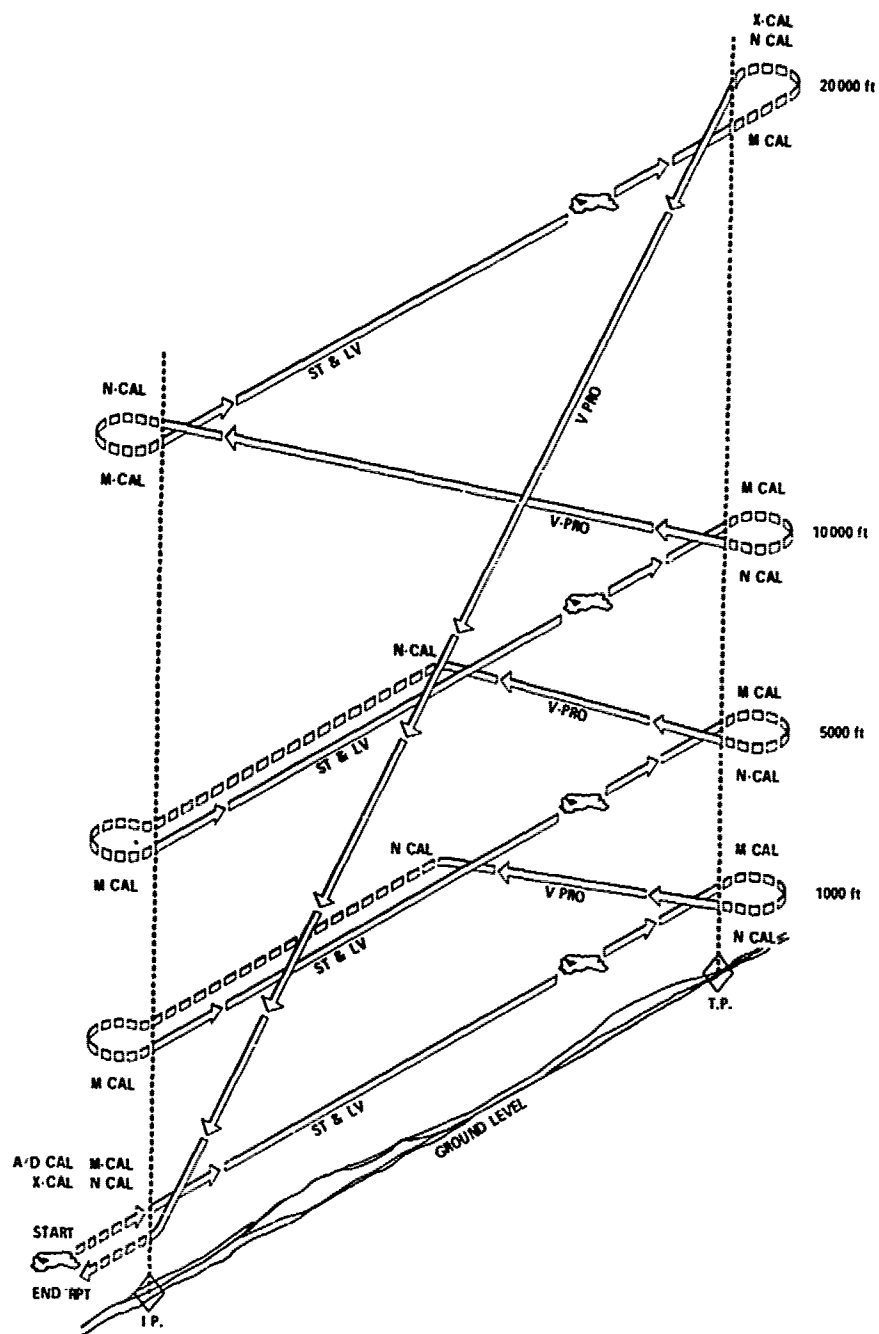


Figure 9. Standard Flight Profile for C-130

2.3 Deployment Summary

For each of the first three deployments, it was planned to fly over at least four, and possibly five, OPAQUE sites. It was expected that in a two-month period of deployment operations about 20 data flights could be launched, considering weather and aircraft maintenance restrictions. Unfortunately, as reflected in the numbers in Table 3, the number of successful data flights in each of these deployments fell considerably short of the expected result. In all cases, the predominant obstacle to more successful deployments was aircraft reliability.

Though more limited in quantity and coverage than originally planned, these data more clearly define the aerosol size distributions and concentrations found over northern Europe in spring, fall, and summer under a variety of weather conditions. The predominant air mass type was maritime polar modified to greater and lesser extent by anthropogenic and continental influences. Only in isolated cases was purely continental air encountered and documented. Tables 4 through 6 present a "by-mission" listing of all data flights for each of these deployments including pertinent mission data and aerosol data quality indicators. Each successful aerosol data set is presented in detail in Section 5.

As mentioned previously, the total program consisted of five deployments. The overall project mission summary is shown in Table 7. The results of the fourth and fifth deployments will be part of a subsequent volume and will not be discussed further in this report.

Table 3. Deployment Summary

Deployment	Inclusive Period	Number of Data Missions	Aerosol Data Sets	Tracks Flown
OPAQUE I	5 April-28 May 1976	10	11	4
OPAQUE II	25 October-6 December 1976	13	13	3
OPAQUE III	4 July-27 August 1977	12	10	3

Table 4. Data Mission Summary - OPAQUE I

Date	Track	Time	Type Mission	Aerosol Sample Altitudes (Alt-km)	General Weather	Air Mass	Stability	Distinct Haze Top (Alt-km)	Comments
12 Apr 76	Soesterberg	1140-1540	Dual 2+4	0.28, 1.5, 3.0, 5.75	Excellent/scattered clouds	CP	Stable	Yes-1.2	Cloud bases 1.8 km. Flight was free of clouds.
1 May 76	Sherborne	1055-1450	Dual 2+4	0.62, 1.57, 3.11, 5.88	Fair/broken clouds	CP	Stable	Yes-1.55	Cloud bases 4.26 km. MP overrunning in approaching front.
6 May 76	Sherborne	1200-1430	Dual 2+3	0.31, 1.15, 2.57	Fair/broken to overcast clouds	MP	Stable	No	
7 May 76	Sherborne	0800-1200	Dual 2+4	0.34, 1.46, 3.0, 6.08	Excellent	MP	Stable	Yes-0.5	Post frontal; stratus dissipated by 0900.
8 May 76	Sherborne	0900-1240	Dual 2+4	0.55, 1.43, 2.99, 6.06	Excellent	MP	Stable	Yes-2.9	Between traveling cyclonic waves; heavy haze below 2.9 km.
10 May 76	Sherborne	0900-1250	Dual 2+4	0.36, 1.46, 2.98, 6.06	Excellent	MP	Stable	Yes-2.3	Haze moderate; scattered clouds above and below.
12 May 76	Rodby	0945-1118	Dual 2+2	0.27, 1.6	Poor/clouds and rain	MP	Unstable	Yes-1.2	
17 May 76	Rodby	1000-1330	Dual 2+4	0.29, 1.61, 3.17, 5.81	Good/scattered clouds	MP	Stable	Yes-1.2	Center of migrating high; cloud bases 1.22 km.
25 May 76	Meppen	1045-1415	Dual 2+4	0.28, 2.11, 3.33, 5.46	Good/scattered clouds	MP	Unstable	Yes-1.55	
26 May 76	Meppen	0920-1100	Dual 2+3	0.33, 3.64, 5.44	Poor/overcast clouds with rain showers	MP	Unstable	No	Post frontal; terminated for weather.

Table 5. Data Mission Summary - OPAQUE II

Date	Track	Time	Type Mission	Aerosol Sample Altitudes (AgI-km)	General Weather	Air Mass	Stability	Distinct Haze Top (Alt-km)	Comments
25 Oct 76	Rodby	1140-1640	Dual 2+4	0.3, 0.6, 1.5, 3.05, 6.1	Excellent	MP	Stable	Yes-0.75	Strong surface flow from NE over Baltic Sea.
26 Oct 76	Rodby	1010-1335	VPRO	0.3, 0.58, 0.71, 5.5	Good	MP	Stable	Yes-0.8	Strong surface flow from NE with low level stratus.
1 Nov 76	Meppen	1040-1330	2+2	0.46, 1.22	Poor/clouds	MP	Unstable	Yes-0.55	Approaching front overcast at 1.52 km.
2 Nov 76	Meppen	0753-1151	VPRO	0.3, 1.52	Poor/rain	MP	Unstable	Yes-0.7	Approaching front overcast at 1.52 km. Broken at 0.44 km. Occasional light rain.
18 Nov 76	Rodby	1027-1405	Dual 2+2	0.3, 0.9	Poor/clouds	MP	Unstable	No	Overcast at 1.07 km. Haze horizontally inhomogeneous.
19 Nov 76	Rodby	1023-1510	Dual 2+3	0.3, 1.83, 4.27	Good	MP	Stable	Yes/low 0.3 km	Strong northerly flow.
22 Nov 76	Meppen	0915-1110	WX Abort	0.33	Poor/clouds and rain	MP	Unstable	No	
23 Nov 76	Meppen	1107-1410	VPRO	0.31, 0.91, 2.44, 4.29	Fair	MP	Unstable	No	In clear-away from showers; strong NW flow.
2 Dec 76	Bruz	1117-1447	2+4	0.42, 0.80, 2.0, 4.4	Fair	MP	Unstable	No	Terminated by approaching front. Gustly strong winds.
3 Dec 76	Bruz	0954-1318	2+2/2+3	0.42, 0.80, 2.0, 4.4	Fair	MP	Unstable	No	Terminated by approaching trough weather. 5.33 km data unreliable.
4 Dec 76	Bruz	0950-1330	VPRO	1.16, 5.33	Poor	MP	Unstable	No	
5 Dec 76	Bruz	1020-1435	Dual 2+4	0.41, 0.89, 2.11, 5.18	Excellent	MP	Stable	Yes-1.5	
6 Dec 76	Bruz	1030-1130	2+2	0.43, 1.05	Fair	MP	Unstable	Yes-1.35	Immediate post trough line.
6 Dec 76	Bruz	1130-1530	Dual 2+3	0.43, 1.4, 3.85	Good	MP	Unstable	Yes-1.35	Post trough line.

Table 6. Data Mission Summary - OPAQUE III

Date	Track	Time	Type Mission	Aerosol Sample Altitudes (agl-km)	General Weather	Air Mass	Stability	Distinct Haze Top (Alt-km)	Comments
4 Jul 77	Bruz	1042-1508	Dual 2+3	0.34, 1.7, 3.2	Good/overcast above w/cumulus below	MP	Unstable	Yes-1.8	Scattered cumulus after 1200L; easterly flow.
6 Jul 77	Bruz	0808-1156	Dual 2+3	0.15, 0.46, 1.7, 2.9	Fair/increasing cloudiness	MP	Unstable	No	Prefrontal heavy haze with no sharp break.
7 Jul 77	Bruz	0809-1310	Dual 2+4	0.4, 1.6, 2.9, 5.6	Excellent	MP	Unstable	Yes-2.4	Heavy haze.
29 Jul 77	Meppen	0944-1250	Dual 2+4	0.15, 0.28, 0.87	Poor/clouds light rain	MP	Stable	No	Overcast cloud bases 2.0 km.
1 Aug 77	Rodby	1015-1540	Dual 2+4	0.18, 0.28, 1.5, 3.06, 4.6	Excellent	MP	Stable	No	Multilayered haze in weak layers.
4 Aug 77	Meppen	0755-1050	VPRO	0.28, 0.45, 0.91	Poor	MP	Unstable	Yes-2.8	Heavy haze with imbedded cumulus clouds-flight flown on Alhorn + Hopsten TACANS.
4 Aug 77	Meppen	1400-1650	Dual 2+2	0.18, 0.26, 0.73, 2.4	Fair	MP	Stable	Yes-1.2	Moderate haze below 1 km AGL; cumulus bases at 1.0 km.
5 Aug 77	Meppen	0800-1247	Dual 2+3	0.15, 0.28, 1.04, 3.06	Excellent	MP	Stable	Yes-1.0	Haze denser top west end of track.
10 Aug 77	Rodby	0930-1440	Dual 2+4	0.12, 0.28, 0.49, 1.5, 3.4, 5.8	Excellent	MP	Stable	Yes-1.5	Haze horizontally inhomogeneous-denser on west track.
11 Aug 77	Rodby	0920-1100	VPRO	0.12, 0.28, 1.56	Poor/clouds and rain	MP	Unstable	No	Cloud base 1.9 km.

Table 7. Overall Project Mission Summary
Aerosol Data Package* Summary for Five Deployments

Site	Season				Total
	Spring	Summer	Fall	Winter	
Northern Germany	2	8	3	3(S) **	16
Southern Germany	0	4	0	6	10
Denmark	2	6	4	3	15
France	0	3	5(W)	0	8
Italy	0	4	0	4	8
Netherlands	1	3(F)	0	3	7
United Kingdom	5	3(F)	0	7	15
Total	10	31	12	26	79

* Table entries represent number of data sets (all available altitudes per set) available from lifetime of aircraft measurement program, 1976-1979.

** Parenthical letters indicate meteorological conditions may have been more representative of the following season.

3. AIRCRAFT INSTRUMENTATION

3.1 Aircraft Capabilities

Instrumented as an optical physics measurement system, U.S. Air Force C-130A, S.N. 550022, was used from 1970 to 1978 on various programs to measure the vertical variation of significant atmospheric optical parameters. In addition to aerosol concentrations and distributions, photometric instrumentation was used to measure the spectral extinction coefficient, upwelling and downwelling radiation fluxes, path radiance, and path function. These optical measurements were made in four spectral bands from 0.45 to 0.75 microns. The optical instrumentation is described by Duntley, et al.^{5, 6, 7}

Additional supporting recorded data included aircraft positional data, significant meteorological parameters, and subjective meteorological and environmental observations. With the exception of the subjective observations and aerosol measurements, all data were recorded in digital form on magnetic tapes to be reduced at a later time. Figure 10 shows the Atmospheric Optics C-130A with the various external sensors indicated.

The references cited above will not be listed here, see References, page 123.

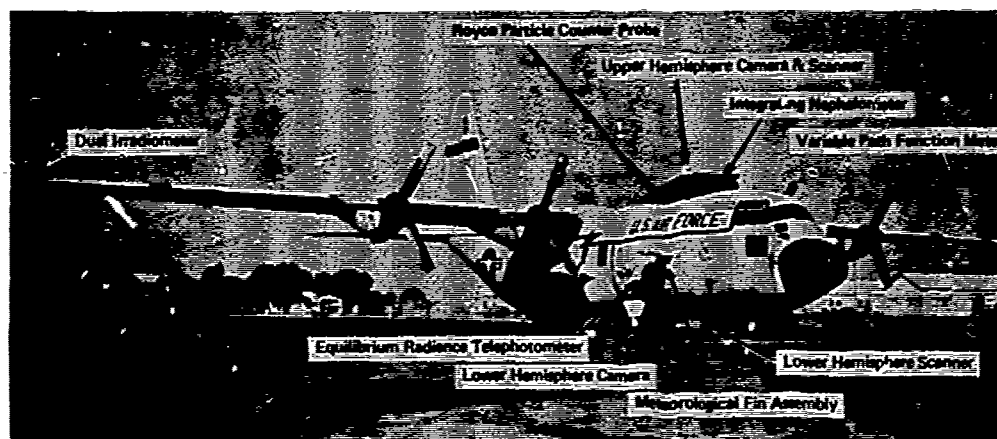


Figure 10. AFGL Flying Optical Laboratory

3.2 Aerosol Measurement Capabilities

Two aircraft measurement systems produced valuable aerosol information. The first was the Royco Single Particle Counter which provided data on both aerosol size distribution and concentration. The second was the 4-band spectral integrating nephelometer which was part of the aircraft's basic optical measurement package and the source of total volume and directional scattering coefficient measurements. Using the nephelometer data in the format of the total volume scattering coefficient provides a high resolution vertical profile of the changing aerosol concentration with altitude. Data from the Royco Counter are used to define specific distributions at various points in the vertical profile. The total concentration measurement determined from the Royco is to be used with caution as discussed in Section 3.3.1.

3.2.1 ROYCO COUNTER

The Model 220 Royco Single Particle Counter System was reconfigured prior to the OPAQUE project to maximize data reliability. As shown in Figure 11, the ram air isokinetic sampling manifold probe was placed on top of the C-130 fuselage with the probe entrance 33 cms above the aircraft skin and 45 cms to the right of the radome (Figure 12). The sampling manifold plumbing was designed to provide as straight a flow as possible to the Royco optical chamber. The exhaust from the optical chamber was returned to the sampling manifold for exhaust to the aircraft exterior. The entire system was completely sealed and pressure tested to insure the prevention of contamination of the aerosol sample by pressurized cabin air. The entire Royco system consisted of the single equipment rack containing the

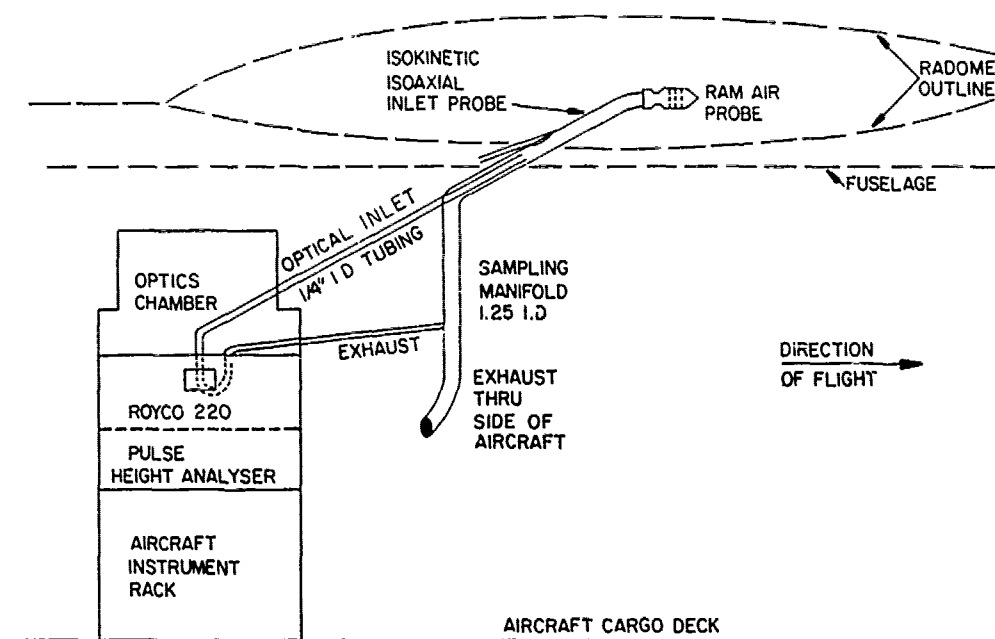


Figure 11. Side View of Royco Sampling System

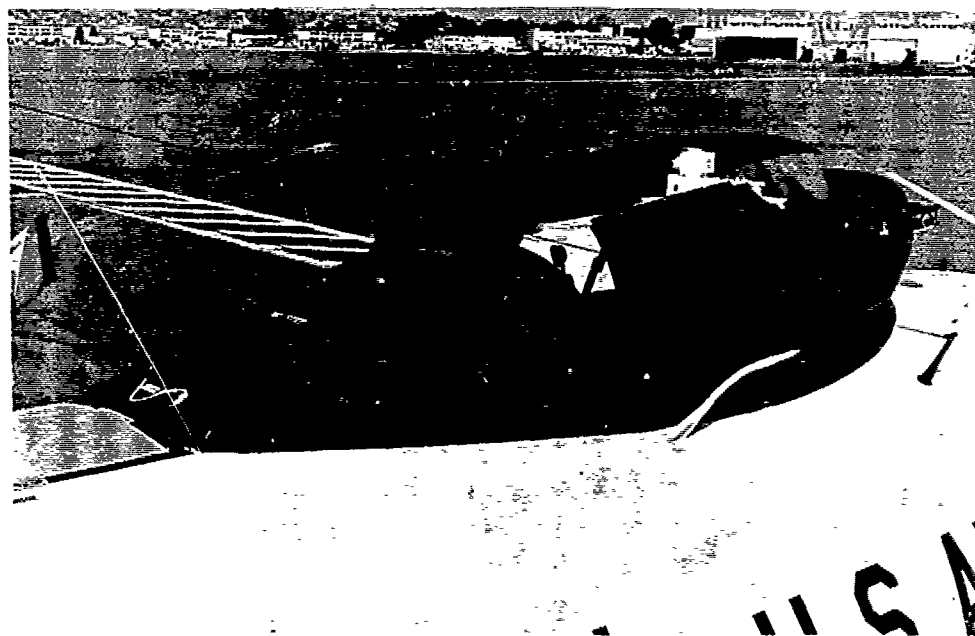


Figure 12. Top Side View of Radome and Royco Inlet Probe

Royco counter (Figure 13), a Technical Measurement Corporation Model 102 Gamma Scope II Pulse Height Analyzer (PHA), and a Hewlett Packard Clock/Printer. Prior to each deployment, the entire system was bench-checked and calibrated component by component. Once installed in the aircraft, the system was again checked, both on the ground and in the air. Prior to installation, and periodically during deployment, monodisperse latex particles were used to establish the instrument's sizing calibration or to confirm that the previous calibration was still valid. If a light source or photomultiplier detector had to be replaced, the entire system was recalibrated. A typical calibration curve determined using latex spheres is shown in Figure 14.

The physical design of the Royco detector assembly is shown in Figure 15. It consists of a white light (tungsten source) illuminator and a photomultiplier detector for measuring the 90° scattering and is limited to detecting particles larger than about 0.4 micrometers diameter; the chopper and light pipe shown in the schematic serve to provide a quick calibration capability.

The light beam is focused to illuminate a 4-mm^3 volume through which the aerosol sample is fed perpendicularly at a volume sampling rate of $46.7\text{ cm}^3/\text{s}$. Considering the diameter of the flow, the effective illuminated volume is 2.63 mm^3 .

For a given combination of white light source and PM detector, the chopper signal "size" is defined by the calibration procedures. Using 0.8-micrometer diameter monodisperse latex spheres, the electronics of the Gammascope were "tweaked" to position the counting of 0.8-micrometer particles in Channel 18; the channel for the "size" of the chopper pulse is then also defined. Since the Gammascope was found to be extremely temperature sensitive, it was determined that a long warm-up was required to reach a stable system temperature; additionally, due to the changing cabin temperature during flight, the system had to be "quick" calibrated prior to each measurement.

Data samples were generally taken for four minutes, but occasionally as short as 60 seconds or as long as ten minutes, depending upon the situation and the density of particles being counted. In general, all data acquired appeared good, subject to the uncertainties discussed in Section 3.3.

3.2.2 NEPHELOMETER

The integrating nephelometer was part of the basic aircraft instrument package designed and built by the Visibility Laboratory, University of California, San Diego, under contract to the Air Force Geophysics Laboratory. The model used during the OPAQUE measurement program was a folded path, white light sensor (an evolutionary instrument) in a light-proof shroud designed to fit under the upper fuselage radome from a late model C-130 (Figure 12). Also discernable in Figure 12 are the four 1.0-inch diameter ram air inlet probes protruding in

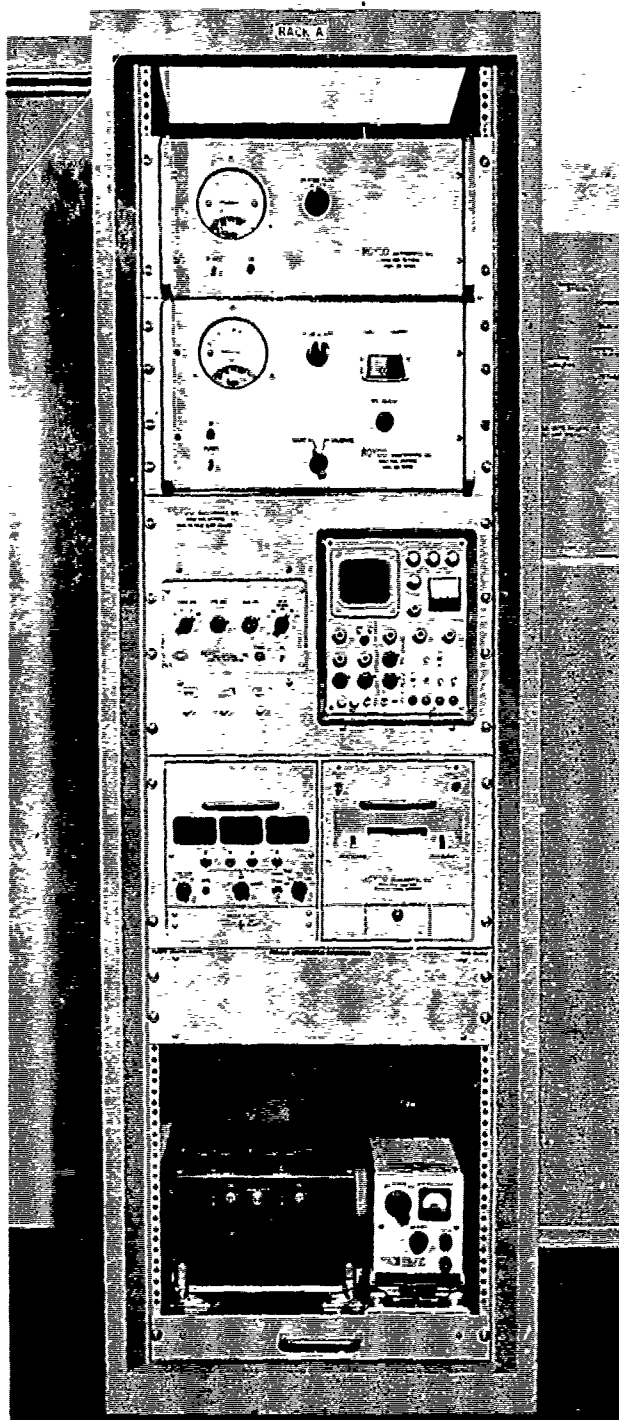


Figure 13. Royco Instrument Rack (Courtesy of Visibility Laboratory University of California, San Diego)

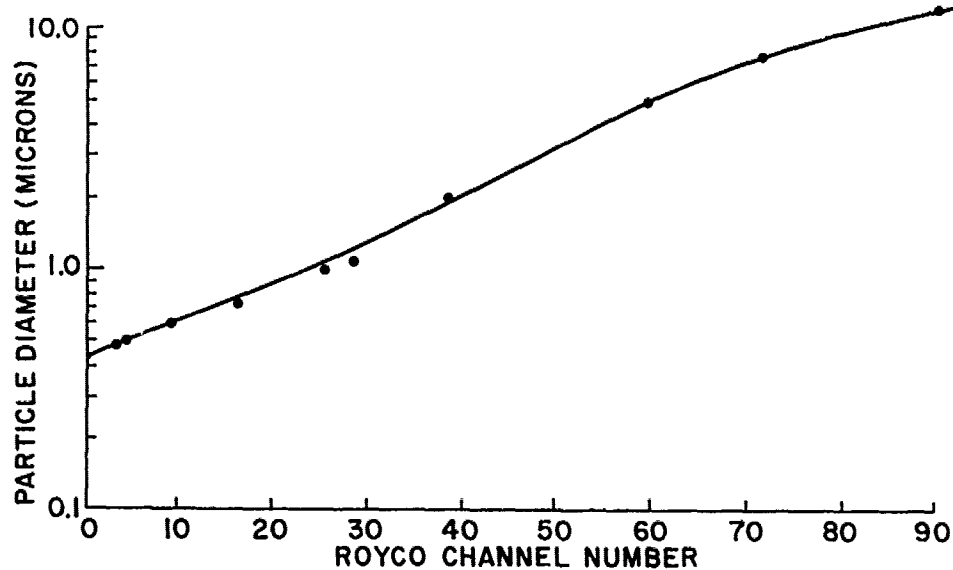


Figure 14. Typical Calibration Curve for the Royco 220 Determined Using Monodisperse Latex Spheres (Plotted Points)

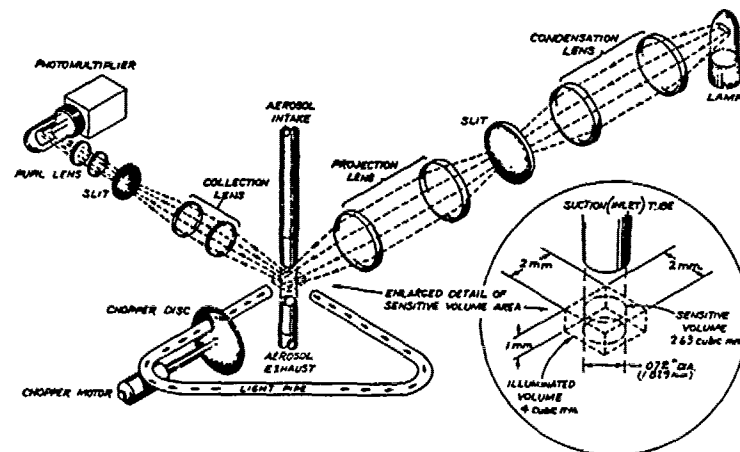


Figure 15. Artists View of Royco Sampling Volume and Detector System (Zinky⁸)

8. Zinky, W.R. (1962) A new tool for air pollution control: The aerosol particle counter, J. Air Pollution Control Assoc. 12:578.

front of the radome, the exhaust ports from the nephelometer at the rear, and the Royco sampling probe to the right side of the radome.

As described by Duntley, et al,^{5, 6} this instrument was designed to measure the total scattering from 5° to 170° using a 2π radiometer, as well as scattered flux in the 30° and 150° directions. Figure 16 shows a schematic of the instrument design. In this report, the total volume scattering coefficient as derived from the 2π irradiator is utilized to define the vertical aerosol structure during the time frame of specific aerosol measurements.

During the field programs with the C-130, contractor personnel maintained and operated all airborne optical instrumentation. All photometer assemblies were calibrated prior to each data mission and after landing. The nephelometer alignment was checked daily; in flight, the calibration was checked and recorded prior to each measurement series. In short, the nephelometer is almost totally reliable, especially with respect to relative changes in the scattering particle density. There are, however, several considerations to be aware of when comparing nephelometer data and aerosol data. These are discussed in the next section.

3.3 Data Uncertainties

The aerosol size distribution and concentration data and the nephelometer derived scattering coefficient data presented in the following sections are reliable and useful within a set of defined bounds. Although the instruments themselves are carefully calibrated and well understood in the controlled laboratory environment, the dynamic and hostile environment of the aircraft involved the installation of these instruments into a sampling system which is not as well understood. Factors and/or discrepancies have been noticed in the data indicating the necessity of being aware of these observations when considering or using the data as presented. This section presents those considerations that were noted during the data reduction which may aid the user.

3.3.1 ROYCO DATA

The Royco 220, originally a clean room monitor and not designed for single particle counting, has been widely used as an optical aerosol sizing and counting instrument. It has, along with other similar counters, received significant attention and has had its capabilities evaluated and compared. Cooke and Kerker⁹ concluded that particle size determination with any of the optical sensing instruments they tested would be "precarious" whenever the refractive index of the particle is unknown. Indeed, in the free atmosphere, the refractive indices of the individual particles are totally unknown. The range of the uncertainty of the sizing

9. Cooke, D.D. and Kerker, M. (1975) Response calculations for light-scattering aerosol particle counters, Applied Optics 14(No.3):734-739.

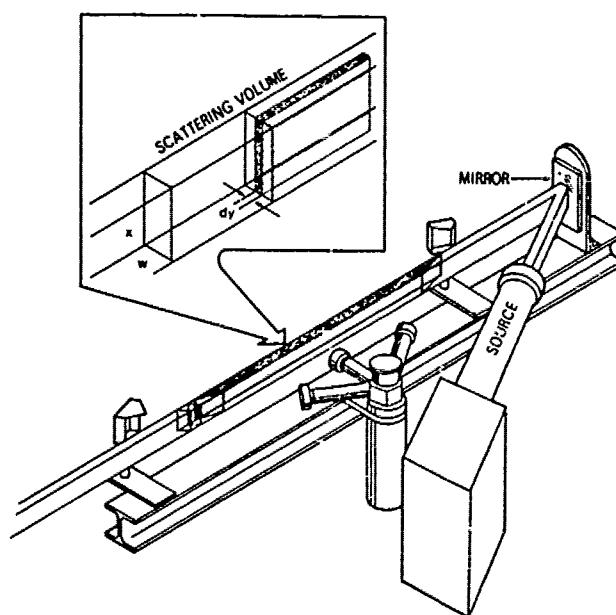


Figure 16. Artists View of Modified Integrating Nephelometer (Courtesy of Visibility Laboratory, University of California, San Diego)

capability of the Royco 220, as shown in Figure 17, does, however, lend itself to reasonable bounds. Quenzel¹⁰ found that refractive index extremes that could occur in the atmosphere (1.33-0.0 i for water and 1.95-0.66 i for carbon) could induce a maximum sizing error of about a factor of 2.4, whereas for the range for water to dry mixed particle the error range is less than a factor of two. Michaels and D'Acierno¹¹ found the Royco 220 performed well in sizing particles of like material when calibrated against monodisperse latex particles. It would appear not to be unreasonable to expect that dry atmospheric particles of mixed composition would not, on the average, vary widely from the 1.49-0.0 i to 1.59-0.0 i range of refractive indices characteristic of the latex particles used for calibration.

Environmentally, an ambient aerosol sample could be strongly affected by its relatively long residence time in the plumbing internal to the aircraft before reaching the Royco scattering chamber. The residence time from nozzle entry to sizing was 1 to 1.5 seconds. Internal aircraft temperatures were nearly always warmer

10. Quenzel, H. (1969) Influence of refractive index on the accuracy of size determination of aerosol particles with light scattering aerosol counters, Applied Optics 8(No. 1):165-169.
11. Michaels, S. C. and D'Acierno, J. P. (1976) Evaluation of Aerosol Generation and Counting Techniques, ORNL/MIT-228, 24 March 1976.

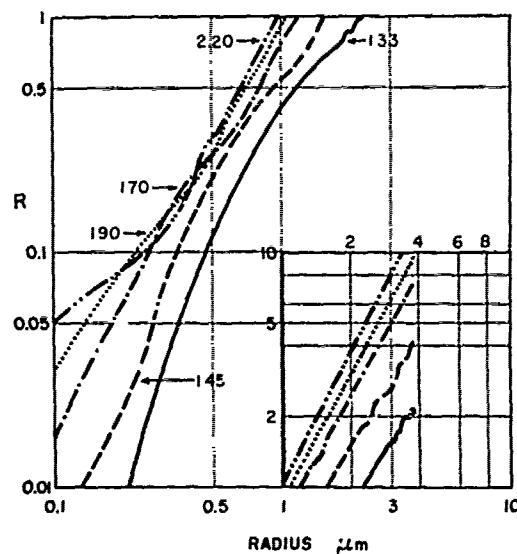


Figure 17. Response of the Royco 220 Particle Counter for Particles with Refractive Indices 1.33, 1.45, 1.70, 1.90, and 2.20 (Cooke and Kerker⁸)

than the ambient air by several to tens of degrees centigrade; the only exception was in Sicily during the fifth deployment where low altitude ambient temperatures were high and relative humidities were very low. In the usual case, the aerosol sample was essentially being passed through a "heater" prior to sizing. It is strongly suspected, as discussed in Chapter 6, that all aerosol measurements made with the aircraft system reflect the "dry" aerosol size distribution and not what naturally existed.

Loss of particles to tubing walls was recognized as a potential influence, but no estimate for the magnitude of this effect is available. Likewise, the possible preferential loss of larger particles is a possibility; the effort to keep changes of flow direction to the barest minimum, isokinetic sampling, and the narrow size range of the sensor's sensitivity, 0.4 to 14 micrometers, should keep this effect small or insignificant.

In terms of direct comparisons, in 1976 the ROYCO was included in an intercomparison of all aerosol counters being used in the NATO OPAQUE ground stations (Cress and Fenn¹²). These were mostly Particle Measurement Systems aerosol probes, both active and classical scattering models. Figures 18 through 21 show the performance of the Royco 220, Probe No. 36 on the abscissa, compared

12. Cress, T.S. and Fenn, R.W. (1978) OPAQUE Aerosol Counter Intercomparison 25 April 1977-4 May 1977, AFGL-TR-78-0004, AD B029 309.

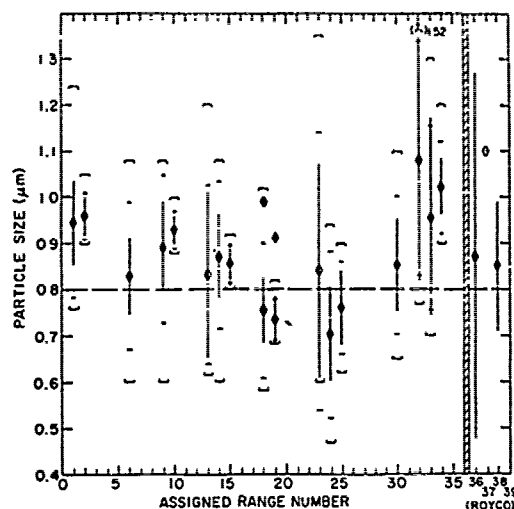


Figure 18. Comparative Aerosol Size Response for PMS and Royco Particle Counters. Aircraft Royco was Probe No. 36. Particle size was 0.801 micrometers

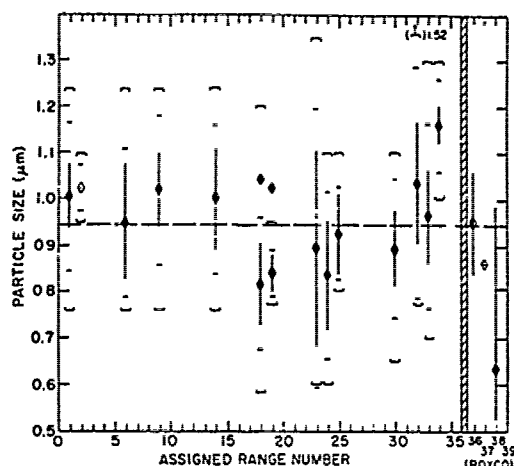


Figure 19. Comparative Aerosol Size Responses for PMS and Royco Particle Counters. Aircraft Royco was Probe No. 36. Particle size was 0.945 micrometers

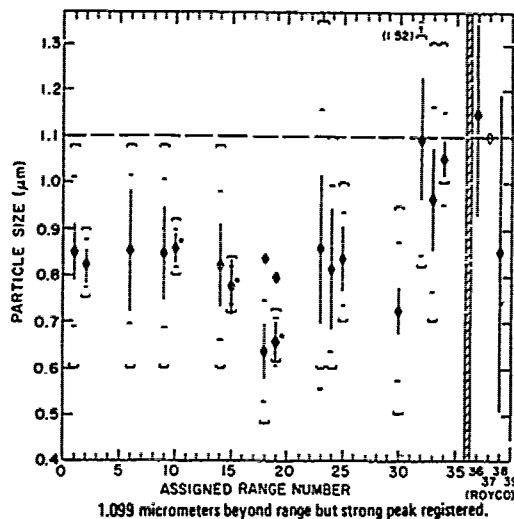


Figure 20. Comparative Aerosol Size Responses for PMS and Royco Particle Counters. Aircraft Royco was Probe No. 36. Particle size was 1.099 micrometers

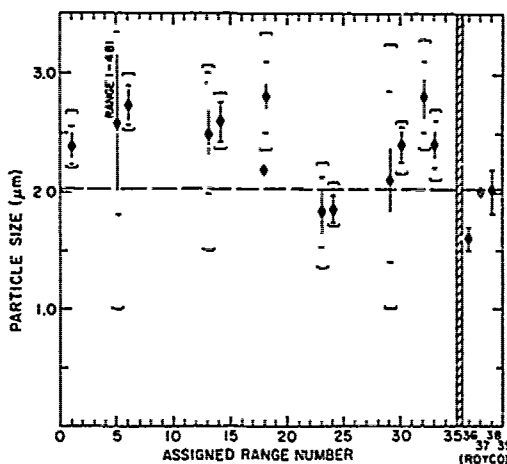


Figure 21. Comparative Aerosol Size Responses for PMS and Royco Particle Counters. Aircraft Royco was Probe No. 36. Particle size was 2.02 micrometers

to the PMS counters for 0.801-, 0.945-, 1.099-, and 2.02-micrometer latex particles. Most dramatic is Figure 20 reflecting the minimal effect of Mie scattering theory on a probe using 90° scattering and a broadband white light source. Figure 22 shows ambient aerosol measurements made by several PMS counters and by the Royco. The Royco distribution compares very favorably with the scatter of the PMS determined distributions. In terms of concentrations it was found that the PMS instruments agreed among themselves to within a factor of two, while the Royco agreed to within a factor of two to five. No real insight was gained into the variability.

The inherent limitations of the Royco counter also create potential sources of error, at least in comparison to nephelometer measurements. The response threshold of the Royco was established to be near 0.4 micrometer, but a degree of intensity nonuniformity across the beam suggests that the reliable lower limit is nearer 0.5 micrometer. Due to the large sampling volume, as depicted in Figure 15, the maximum permissible concentration for single-particle detection is about 100 particles/cm³ for particles larger than 0.4 micrometer. Larger concentrations lead to larger errors in both size and concentration determinations (coincidence errors).

In dense aerosol conditions a frequent number distribution characteristic is a peak at very low sizes; for example, 25-26 October 1976. Although it is possible for a peak to exist under these conditions, the magnitude of the decrease toward the lower limit of the Royco's range is unreasonable. The author strongly suspects that a combination of factors, including coincidence measurements (that is, multiple particles or beam) and small particle losses via collection by larger particles because of differential velocities induced by acceleration, probably accounts for this decrease. Within the plumbing system, these suspicions have not been substantiated but caution should be observed in dealing with particle concentrations at sizes less than the peak in the distributions.

The refractive index ambiguity is a real effect, but it would not seem unreasonable to conclude that the more mixed character of aerosol particles having passed through a wet stage probably minimizes the net refractive index ambiguity from the maximum possible, that is, carbon to water. Confidence can probably, therefore, be expressed in the general shape of the size distribution as measured, especially in the intermediate part of the sensitivity scale, 0.8 to 3 micrometers. Less confidence can be expressed in total concentrations due to possible significant losses in the plumbing system and a potential for noncounting of very small particles due to coincidence or capture.

A concise listing of recognized potential influences is as follows:

- (1) Possible losses in the aircraft sampling system.

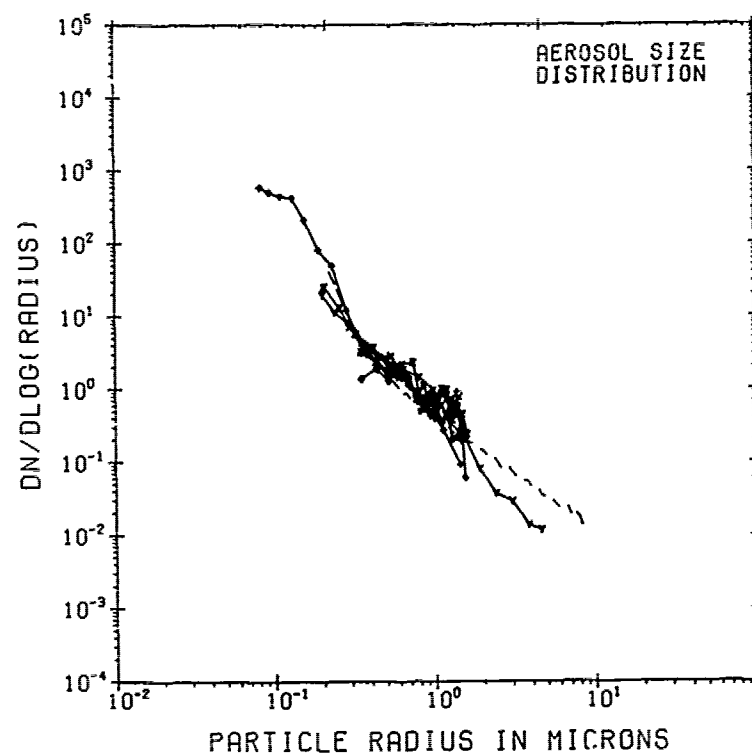


Figure 22. Ambient Aerosol Distributions Measured by Active Scattering PMS Particle Counters (Solid Lines) and the Royco 220 (Dashed) During Near Ground Level Laboratory Testing

(2) Possible (probable) drying of particles drawn from relative humidity environments of 60 percent or greater.

(3) Possible (minimal) selective losses of larger particles.

(4) Possible contamination by aircraft cabin air through leaks in the sampling system.*

3.3.2 NEPHELOMETER DATA

Like the Royco data, the carefully controlled testing of the nephelometer outside of the aircraft indicates high reliability and accuracy. In flight, the necessity to draw the aerosol through the inlet sampling tubes, possible pressure differentials along the air flow path through the nephelometer, and possible temperature

* In-flight monitoring and careful data scrutiny have identified occasional leaks during the fourth deployment. No such problems were noted in Deployments I, II, or III covered in this report.

differences between the nephelometer interior and the ambient air all raise valid questions as to the effect upon the resulting measurements. Cross comparisons between the aircraft nephelometer and a similar ground instrument show close agreement both in side-by-side measurements and low and slow "fly-bys" by the aircraft over the ground instrument. This lends a great level of credence to the aircraft nephelometer data, but influencing factors may still be significant, especially in specific cases like the high relative humidity environment.

Overall the nephelometer data can be accepted as is but may need secondary consideration in unusual or extreme (high humidity) environmental conditions. If all factors were considered at their worst, this data would still be accurate within 50 percent.

4. DATA ACQUISITION

During a standard full mission, the C-130A flew a series of straight and level sequences (SL) and vertical profile (V-PRO) ascents and descents similar to the pattern described in Figure 9. The standard profile began with an SL pass at 300-400 m above ground level (AGL) and continued with V-PRO climbs to about 1600 m, 3200 m, and 6000 m with an SL pass at each altitude. This full sequence is known as a 2+4 profile referring to data taken in two filters at four altitudes. Optical data was required in four different spectral bands necessitating a second such profile to be flown. A full mission was then referred to as a Dual 2+4 and required 3.5 to 4 hours to complete. The duplication of aerosol data at four altitudes, though temporally displaced, provided redundant data under static conditions but, during periods of rapid change, permitted the comparison of aerosol data from essentially different air masses. SL passes were flown at 145 kts IAS (indicated airspeed necessitating the track length of some 50 km).

The evaluation of some of the aircraft optical measurements (path and sky radiance) required a degree of uniformity of cloud coverage along the entire 50-km track; thus, the full Dual 2+4 Profile could be flown on only very good days, that is clear of clouds at all levels, not more than a few eighths coverage below 6 km, and uniform coverage or overcast (uniform illumination) above the highest altitude flown. The ideal conditions were either a clear day or a uniform overcast above 6 km.

In less than ideal conditions, alternate flight patterns were devised to get the most out of a given day. These included a Dual 2+2 profile below an overcast and a V-PRO series for nonuniform days or days when the 50-km track could not be flown without significant deviation because of clouds or weather. The V-PRO series was flown to obtain only the vertical profile of the scattering coefficients for the four filters.

4.1 Nephelometer Data

Two modes of nephelometer data were taken during the standard profile; continuous data during a SL and continuous data during a climb or descent. For this report, only the vertical profile, that is, climb and descent data, is used. Vertical profile data were taken during every mission regardless of type of profile, duration, and whether or not it might have been terminated early due to weather. These data were reduced from tape and are presented in a continuing series of reports (Duntley, et al^{13, 14, 15}) prepared by the Visibility Laboratory as part of a contract with the Air Force Geophysics Laboratory. The profiles are used here to give context to the individual Royco determined size distributions and concentrations.

4.2 Royco Data

Royco data were taken during each SL segment of whatever profile was being flown. Four minutes became the standard sampling time during the second (fall 1976) deployment and continued through all the remaining field projects. Ten-minute samples were the standard during the spring 1976 deployment and were occasionally used thereafter for high-altitude measurements where particle counts were very low. Occasional 60-second samples were taken during short descents to as low as 100 meters.

Due to the nature of the Dual 2+4 Profile, two sets of aerosol data (a "set" consisting of one sample from each altitude) were taken for each Dual Profile. Under stable conditions the second set now provides a check upon the data in the first set or provides a backup data set in case of a problem determined to exist during one of the sampling runs. Although each set of altitude data required about 1.5 hours to collect, it is assumed that the data set is a close approximation to the instantaneous vertical variation of the aerosol size distribution. Each data set is

13. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1977) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Spring 1976, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 77-8, AFGL-TR-77-0078, AD A046 290.
14. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1978a) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe Summer 1977, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 78-28, AFGL-TR-78-0168, AD A068 611.
15. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1978b) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Fall 1976, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 78-3, AFGL-TR-77-0239, AD A057 144.

identified by the starting time of the earliest (usually lowest) measurement. Cases of rapid change are discussed in a later section as well as examples of the temporal and spacial consistency of the aerosol data at a given altitude under stable conditions.

5. AEROSOL DATA SUMMARY

5.1 Deployment Summary

5.1.1 SYNOPTIC WEATHER PATTERN SUMMARIES

(1) OPAQUE I, 5 April–28 May 1976. Timed to document European spring atmospheric optical properties, OPAQUE I was reasonably successful considering the range of conditions encountered. April was much sunnier and drier than normal, while May was much cloudier and wetter than normal. From 1 April through 7 April, upper level troughing west of Great Britain and France allowed occasional frontal systems trailing from storm centers passing north of Great Britain to penetrate well into southern Europe introducing surges of fresh maritime polar air. From 8 April through 26 April, a strong upper level blocking ridge over Europe and the North Sea steered all but an isolated frontal system well north, thence southward over Scandinavia and Russia. Only England and Denmark were close enough to the boundary of the shielded area to experience a few weak frontal passages and air mass changes. Through the mid-April period, air mass domination over continental Europe fluctuated between ridges of the Azores high and the Siberian high. Consequently, though no significant frontal passages occurred, the dominating air mass characteristics fluctuated through a wide range. Occasional periods of stagnating air masses occurred with associated reductions in optical transmission. Outside of a minor break in the pattern on 27 April, the strong ridging did not completely break down until the first of May. From 2 May through the end of the deployment, Europe was totally dominated by a traveling cyclone regime. Frequent frontal passages were experienced by all of northern Europe, with each new air mass essentially similar to the preceding. Changing optical conditions, in this type of regime, were dominated by relatively local effects associated with the actual overland trajectory followed by the advancing air mass.

(2) OPAQUE II, 25 October–7 December 1976. The fall season deployment occurred during a relatively consistent period of synoptic conditions. The dominating feature was a persistent deep upper level trough either over the North Sea and continental Europe or just to the west of France. Thus the storm track was well south and, except for the periods 25–30 October and 19–23 November, all of Europe was buffeted by a continual series of troughs and fronts associated with

rapidly migrating storm systems passing just north of Great Britain. The two short respites were associated with minor ridges in the upper atmosphere resulting in slowly migrating ridges of high pressure at the surface. All air masses experienced during the deployment period were, in origination, maritime polar and, due to the rapidity of movement, maintained strong maritime characteristics. The end results were slightly cooler temperatures than normal, significantly greater cloudiness, more days of precipitation, but about average total rainfall; for example at Meppen 50 percent of expected hours of sunshine but 90 to 110 percent of normal rainfall in the surrounding area.

(3) OPAQUE III, 4 July–11 August 1977. The summer season synoptic pattern dominating during OPAQUE III included two primary patterns. From 1 through 13 July, a strong blocking high at upper levels protected Great Britain and the continent from significant frontal systems and, consequently, significant air mass changes. Early July was, in general, warmer and drier than average across most of Europe. After 13 July, however, the upper level blocking high disintegrated, followed by a broad, poorly defined and persistent upper level troughing. This pattern persisted through the early termination of deployment flights on 11 August. In association with the poorly defined upper level patterns, the entire European theater area was a persistent region of weak gradients, diffuse and ill-defined fronts, stagnating frontal systems, indistinct air masses and only isolated occurrences of strong air mass movements from the Atlantic Ocean. The general cyclonic flow of cool air aloft maintained highly unstable conditions resulting in a general cloudiness and frequent showers. Southern Denmark, for example, was in a persistent pattern of light rain throughout late July and early August resulting in many more than normal days of rain, but still the total rainfall was within 5 percent of average. Northern Germany was slightly drier and cooler than normal, but with a significantly fewer number of hours of sunshine. Air mass differences during this entire period were not distinct but, due to long residence times and trajectories over continental areas, should show strong continental influences superimposed on originally maritime air masses.

5.1.2 SEASONAL REPRESENTATIVENESS

Although this report makes no effort to statistically determine the representativeness of actual data cases to mean seasonal characteristics, a cursory comparison of the predominant upper level flow patterns to the mean flow pattern will indicate a major departure from seasonal characteristics. Figures 23a, c, and e are the mean 500-mb patterns for May, November, and August as presented by Lahey, et al¹⁶ for the European area. Figures b, d, and f are 500-mb charts

16. Lahey, J.F., Bryson, R.A., Wahl, E.W., Horn, L.H., and Henderson, V.D. (1958) Atlas of 500 mb Wind Characteristics for the Northern Hemisphere, AFRCR-TN-57-602.

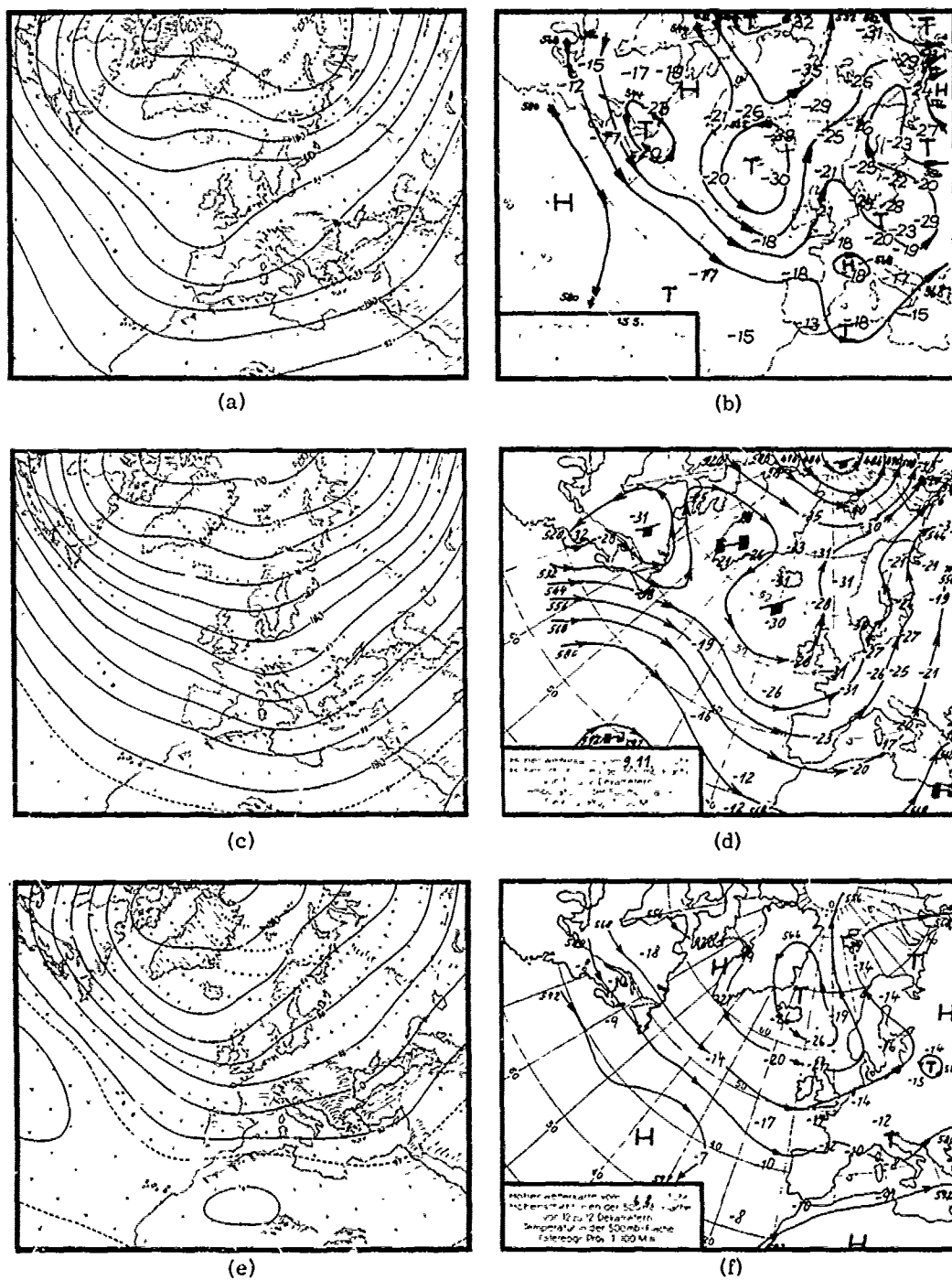


Figure 23. 500 mb Mean Patterns (Lahey, et al¹⁶) for May (a), November (c) and August (e) for Comparison to 500 mb Patterns Existing on 15 May 1976 (b), 9 November 1976 (d), and 6 August 1977 (f)

prepared by the Deutscher Wetterdienst for 15 May 1976, 9 November 1976, and 6 August 1977. These plots were subjectively picked as somewhat representative of the predominant flows during the OPAQUE data periods. It is important to realize that the mean 500 mb charts represent the average of a wide range of individual patterns and should be compared with specific days cautiously. The following discussions of the individual deployments do indicate that no significant parts of the individual data sets were acquired under significantly extreme or unusual synoptic conditions.

(1) OPAQUE I (Figures 23a and b). The 500-mb trough position during OPAQUE I, as indicated by the 15 May 1976 chart, agrees well with the mean trough position for May; however, the zone of maximum winds is along 50°N latitude whereas the mean position for May is well to the south. This combination of synoptic features would suggest low pressure intensification at about the same longitudinal position as the average, but much farther north. The result over Europe would be the passage of less active, less distinct, and weakening trailing frontal surfaces instead of sharply defined fronts and distinctly different air masses. The secondary feature of the mean 500-mb flow (its less uniform pattern than other monthly mean flows) suggests a much wider variation of height fields in the spring with significant occurrences of high-pressure ridging over the North Sea. This mean feature could be correlated to the predominate ridging observed in April and early May.

The relationship of the April-May 1976 period to the average conditions for these months can be subjectively summarized as a period without a major separation from the probable range of spring conditions, with the exception that surface synoptic systems over Europe in May 1976 probably moved a little slower with less distinct changes than in a typical year. Since year to year variations can be quite significant, there is no reason, based upon these observations, to suspect that data from April and May 1976, would not be representative of a more or less typical year.

(2) OPAQUE II (Figures 23c and d). The closely packed contours of the 500-mb mean chart for November strongly suggest the repeated occurrence of rapidly moving surface cyclonic systems with frequent frontal penetrations through continental Europe and into the Mediterranean basin. The 500-mb chart for 9 November 1976, as somewhat typical of the OPAQUE II period, would suggest, similarly, the frequent passage through Europe of distinct low pressure centers and distinct frontal systems. Unlike the suggestion of the mean flow, however, the 9 November 1976 chart indicates a distinct trajectory of low-pressure systems northward over central and eastern Europe with the result of long, slow moving trailing frontal systems over this area and more persistent poor weather conditions.

Despite this trajectory difference over eastern Europe, the general conditions over western Europe show an apparent good correlation to the average and should be relatively representative of typical November conditions.

(3) OPAQUE III (Figures 23e and f). The mean 500-mb flow in August suggests conditions over northern Europe similar to November, with only slightly less frequent and less intense frontal activity. In marked contrast, however, the storm center track is far to the north, and frontal systems would rarely reach into the Mediterranean, and then only weakly. The actual conditions reported on and near 6 August 1977 are markedly similar in all major respects. Thus, it can be subjectively concluded that the data taken during OPAQUE III should be applicable to the bulk of summer conditions.

5.2 Case Study Data

5.2.1 CASE STUDIES VERSUS SEASON

Although each data set acquired during this program is a distinct and separate entity, the generally stable character of the European atmosphere and apparent seasonal representativeness permit the valid use of these case studies in various groupings to investigate more "average" vertical profiles and size distributions than acquirable from a single data set. This report does engage in some simple studies in Section 6 aimed at bulk characteristics of each season's data sets. The primary purpose is to look at the representativeness and reliability of the data presented. The major point to be made is that such studies are possible to develop new, or refinements to old, aerosol models.

5.2.2 CASE STUDY DATA

Each data flight is presented as a complete data set comprised of a narrative presenting dates, times, weather, air mass, and flight conditions for each measurement, and figures showing aerosol distributions, vertical variation of total volume scattering coefficient, and synoptic surface weather. The last column of the data tables indicates the least squares fitted straight line slope through data points for radii larger than 0.4 micrometers. If two aerosol data sets were taken in conjunction with a dual profile type flight, both data sets are presented. Additional data for each flight can be found in the corresponding Visibility Laboratory report on scattering coefficients (Duntley, et al^{13, 14, 15}).

OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Soesterberg - 12 April 1976

Time Period of Flight: 1140-1540 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1205	280	600	25.31	45-65	-3.23
1226	1500	600	15.97	85-90	-3.06
1246	3000	600	0.63	15-70	-1.80
1344	5755	600	0.36	50-60	-1.88

Second Data Set

1354	280	240	24.57	35-65	-3.17
1420	1500	600	15.40	80-95	-3.00
1456	3000	600	0.42	20-25	-1.82
1526	5755	600	0.36	<40	-2.09

Synoptic Meteorological Summary

The surface chart for 0000 GMT, 12 April 76, shows high pressure ridging was dominating all of continental Europe, with easterly to northeasterly surface winds and clear skies. A moderately strong frontal system to the west was being held back by strong upper level ridging over Russia, causing the surface low-pressure track to be from Iceland to northern Norway. The pattern was stable, with no major changes impending for the Soesterberg area. Meteorological characteristics were cool, dry air, stable conditions, clear skies and good visibilities.

Air Mass Summary

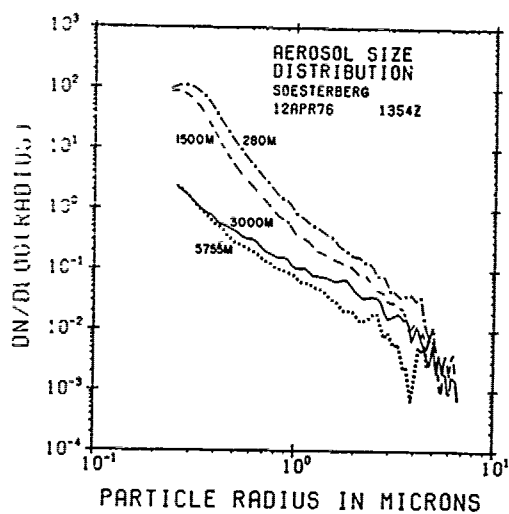
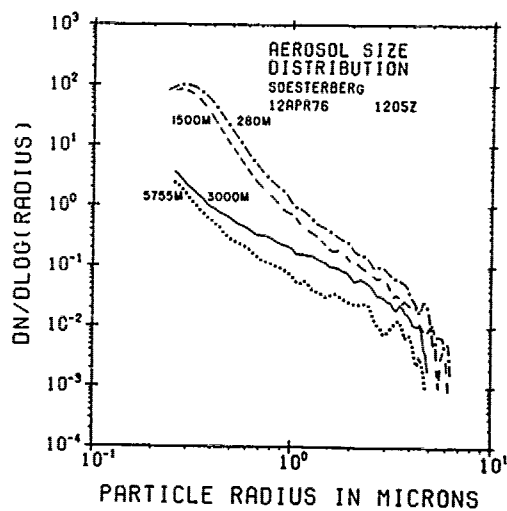
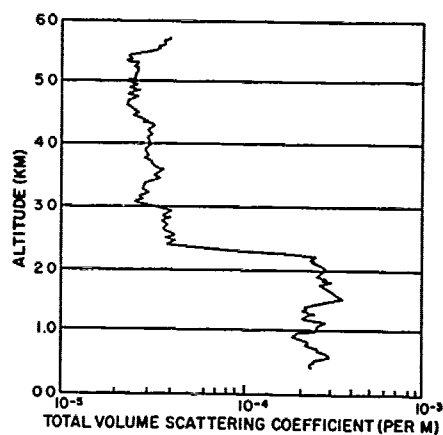
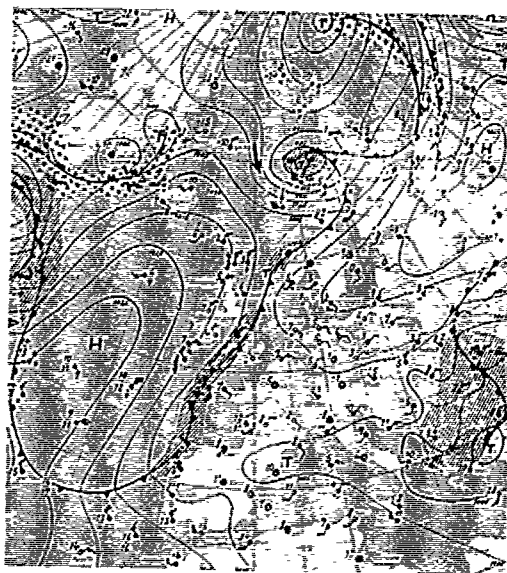
No frontal surfaces had passed Soesterberg during the previous 4 days. The surface ridging was originally associated with the Atlantic high, a modified maritime tropical air mass, but with strengthening of the Siberian high and a sharp trough aloft over France, the circulation over the North Sea coast gradually shifted to dominance by the Siberian high. This day was the first day of a clear-cut continental circulation and should be considered as dominated by continental polar influences with possible traces of previous maritime air mass characteristics.

Flight Summary

Upon arrival in the track area, conditions were found to consist of one-eighth of stratocumulus clouds based at 2000 m with a distinct haze layer below. Heavier haze was observed on the west end of the track. Above 2000 m, it was clear with no apparent haze. Surface visibility at Soesterberg AB, near the western end of the track, was 11 km; Deelen, to the east, was reporting 18 km. During the period of the flight, the stratocumulus cloud coverage gradually increased to three-eighths coverage by 1400 GMT with visibilities at both Soesterberg and Deelen improving to 20 km or greater. Cloud vertical development was very limited. Surface temperatures were 15 to 16°C with dewpoints of -1 to -2°C.

Aerosol Data Comments

Aerosol measurements were made at two levels below the top of the haze layer and at two levels in the clear air above. The graphed samples show the distinct separation between the two environments. Samples taken at 280 m AGL on the west and east ends of the track, 1445-1500 GMT, were nearly identical despite apparent observed differences in haze densities during this period.



OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Sherborne - 1 May 1976

Time Period of Flight: 1030-1530 GMT Type of Data Flight: Dual 2-4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu m$
1127	1570	317	2.43	65-70	-2.05
1203	3110	600	0.37	90-100	-1.77
1233	5880	600	0.13	100	-1.47

Second Data Set

1303	620	578	8.28	45-60	-2.81
1330	1570	600	3.89	45-60	-2.47
1404	3110	600	0.29	65-95	-2.00
1432	5880	600	0.14	100	-1.75

Synoptic Weather Summary

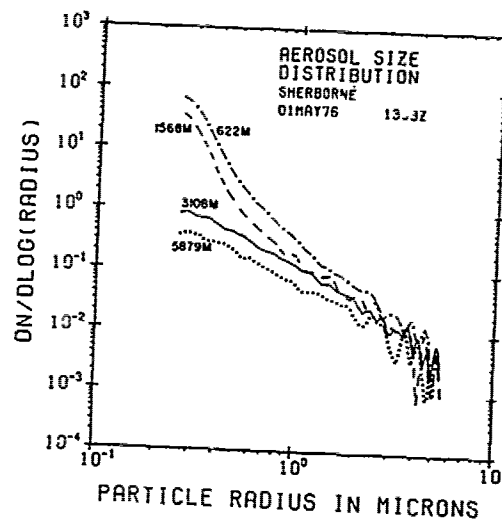
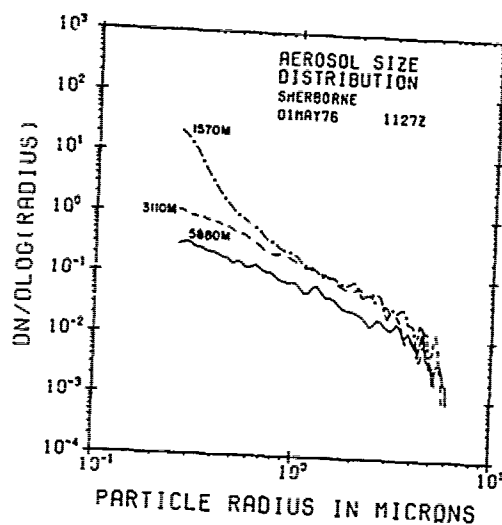
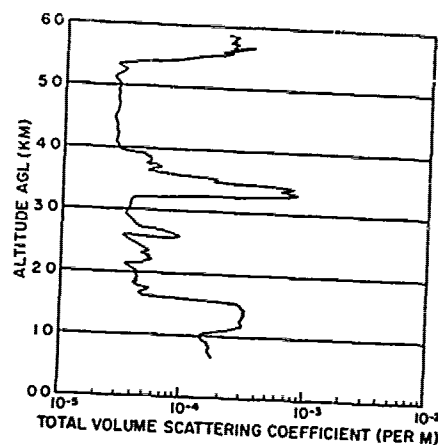
This day marked the end of an upper level blocking ridge over the UK which had protected the UK by guiding low-pressure systems from the mid-Atlantic to Iceland and southeast over the North Sea. Frontal systems were blocked from the islands by surface high pressure extending in an arc from the Azores to Lands End, London, the Netherlands, central Germany, and western Russia. As an extension of the Azores high, the surface ridge was maritime in origination, but as the ridge elongated into Russia, continental influences become dominate in the easterly flow south of the ridge axis. Thus the north side of the ridge axis was dominated by maritime influences, while south of the axis dry, cool continental air dominated. On 1 May, the Sherborne track was on the ridge axis and subject to wide variations in the indistinct boundary between the maritime and continental flow. To the west, a weak occluded front was slowly approaching, increasing the cloudiness in the maritime air flow.

Air Mass Summary

The dominating air mass along the track at any given time was an unknown and may have fluctuated. In-flight observations, however, indicate a degree of consistency along the track in space and time. Given the degree of cloudiness and high relative humidity of the first data set, it was most likely dominated by maritime air. The data from the second data set do indicate a tendency towards drier air. Surface observations at Yeovilton, 10 km north of the track, and at Bournemouth, 30 km southeast of the track, tend to suggest that maritime air was more dominant during the measurement period, but with a tendency towards more continental air.

Flight Summary

During the period of the flight, both Yeovilton and Bournemouth reported extensive cirrus cloud coverage with persistent altocumulus and altostratus below. Both stations reported southwest winds and temperatures of 12 to 14°C. Major differences, indicating basic air mass differences at the surface, were dewpoints of 9 to 10°C with visibilities of 8 to 12 km at Yeovilton, while at Bournemouth the air was drier and clearer, with dewpoints of 0 to -4°C and visibilities of 25 km. Upon arrival in the track area, the aircraft found overcast cirrus with patches of cumulus clouds over higher terrain. During the flight, coverage of altocumulus/altostratus increased in the 4500- to 6500-m AGL altitude range. The first flight at 5880 m encountered patches of altostratus, while the second flight at 5880 m was in the clear, between altostratus layers. The surface-based haze layer topped at 1500 m.



Aerosol Data Comments

All aerosol measurements were made in clear air. The lowest data sets were distinctly within the surface-based haze layer, while the data above 1600 m were free of observable haze. The data near 1570 m may be the integration of the aircraft passing through fluctuations at the top of the haze layer.

OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Sherborne - 6 May 1976

Time Period of Flight: 1100-1430 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1159	1150	495	2.20	40-60	-2.36
1224	2570	600	0.59	100	-2.21

Second Data Set

1251	310	285	18.37	85-90	-3.67
1320	1150	600	1.17	45	-2.25
1347	2440	600	0.91	80-85	-2.24

Synoptic Weather Summary

The surface map for 5 May shows the remains of a slow moving and weakening storm system that dominated southern England, western France, and the western approaches to the English Channel. Well defined 24 hours earlier, the low-pressure system and its associated weather continued weakening on 6 May 76, resulting in an ending of precipitation, but extensive cloudiness over all of southern England. At upper levels, the 500-mb chart shows a deep trough west of France, with a ridge over England and the low countries.

Air Mass Summary

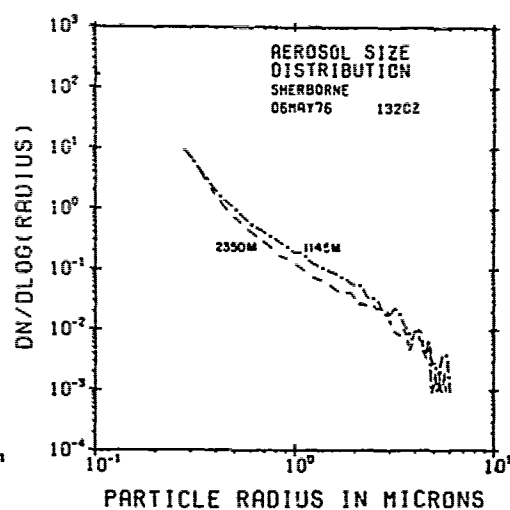
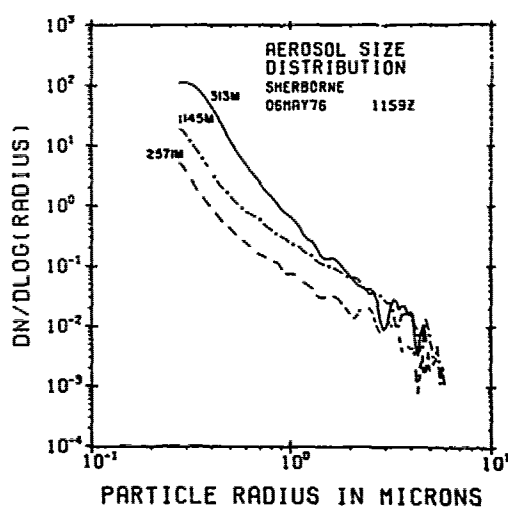
The dominating air mass on the Sherborne track was maritime, but with the easterly to southeasterly flow ahead of the frontal system, the air mass was likely a continentally modified maritime air mass, at least at low levels.

Flight Summary

Upon arrival in the track area, the aircraft found overcast conditions, with cloud bases at 3300 m. A surface-based moderately dense haze layer was observed with a top at about 800 m. Visibility within the surface layer was estimated at 5 km. These conditions were persistent through the data period.

Aerosol Data Comments

All data were taken free of clouds, except for the first 2570-m data set; the last two minutes of this data set were taken as the aircraft skimmed the overcast base, in and out of cloud patches. Data indicate little or no influence, probably because cloud droplets are too large to get through the Royco plumbing system. Only the one 310-m data set was taken in the surface-based haze layer which topped at 800 m.



OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Sherborne - 7 May 1976

Time Period of Flight: 0730-1300 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0816	340	600	26.53	65-75	-3.52
0855	1450	600	2.41	65-85	-2.42
0923	3000	600	0.48	70-75	-2.34
0954	6080	1134	0.29	35-55	-2.28

Second Data Set

1031	340	418	37.11	80-85	-4.29
1101	1450	852	2.62	75-100	-2.40
1125	3000	540	0.48	80-95	-2.38
1154	6080	252	0.08	30-60	-1.63

Synoptic Weather Summary

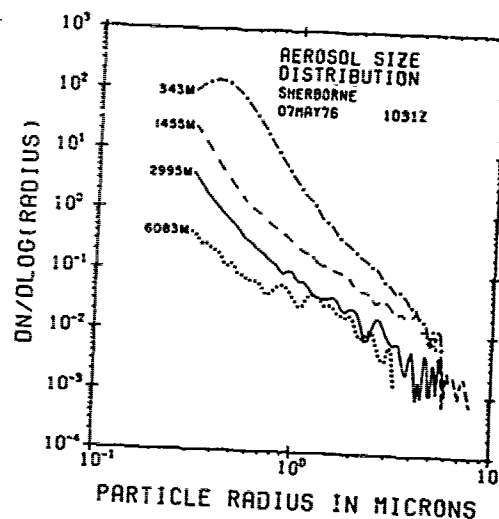
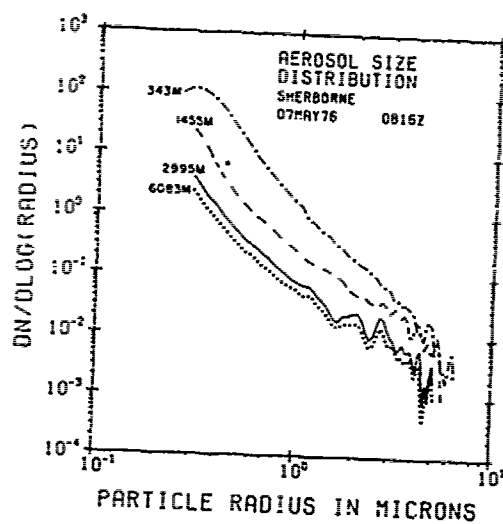
The deep trough at the 500-mb level on 6 May extended itself southward, becoming cut off south of Spain, and was no longer an influence in southern England. Weak ridging at upper levels continued to dominate, though less strongly than on 6 May. The surface map shows high pressure over the North Sea, with a weak and diffuse frontal surface over central England, Holland, and Northern Germany. South of this frontal surface, skies are mostly cloud free while scattered clouds are indicated north of the front over the North Sea. A stronger low is shown near Ireland, with a long trailing frontal system moving into Ireland. At 0000 GMT, this system was too far west to be a factor in the Sherborne area. Additionally, the upper level ridging continued strong enough to force the frontal system northwards, with only very weak influences over southern England much later in the day.

Air Mass Summary

At all altitudes, the air mass movement was weak from the south or southwest. The Sherborne track remained on the axis of a series of weak high-pressure ridges from the Azores high to Denmark. Thus, low-altitude air mass characteristics were not purely maritime, but had significant continental modifications, for example, dense low-altitude haze.

Flight Summary

Upon arrival on track at 0800 GMT, the aircraft found overcast stratus in the western one-half of the track. The remainder of the sky was clear. The low stratus, tops 300 m AGL, dissipated completely by 0930 GMT. After 1000 GMT, cirrus clouds increased to three-eighths and dissipated. Multiple layers of haze were observed with a very dense surface-based haze topping at 650 m and other significant and separate haze layers observed between 1300 and 6000 m. Visibility at Yeovilton was reported to be 3.5 km at 1100 GMT.



Aerosol Data Comments

Only the 340 m AGL data sets were clearly within the dense, surface-based haze layer. In-flight observations indicated that the 1450-m data sets may have been within one of the elevated haze layers, but that it was difficult to be sure. Similar doubts existed for each of the higher samples, except there was a degree of confidence that the 3000-m sample was relatively clear of a distinct haze layer.

OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Sherborne - 8 May 1976

Time Period of Flight: 0900-1240 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0904	550	244	19.34	80-90	-3.47
0935	1430	600	1.54	40-45	-2.42
1011	2990	322	1.92	60-100	-2.43
1029	6060	600	0.12	50-55	-1.90

Second Data Set

1102	550	592	22.33	90-100	-4.01
1127	1430	600	1.38	45-50	-2.48
1155	2990	506	1.49	40-70	-2.56
1218	6060	271	0.10	40-75	-1.96

Synoptic Weather Summary

Upper level ridging continued to keep low-pressure systems and strong frontal activity well to the north of the UK. The surface chart for 0000 GMT 8 May 76 shows a series of weak fronts, generated by the deep Icelandic storm system, which were passing over the northern UK. Only very weak influences, such as slightly increased cloudiness, were observed in southern England. On 8 May, a weak system passed, with another approaching. Little or no cloudiness was associated with either system, and no true air mass change occurred. Weather on 8 May was stable and consistent.

Air Mass Summary

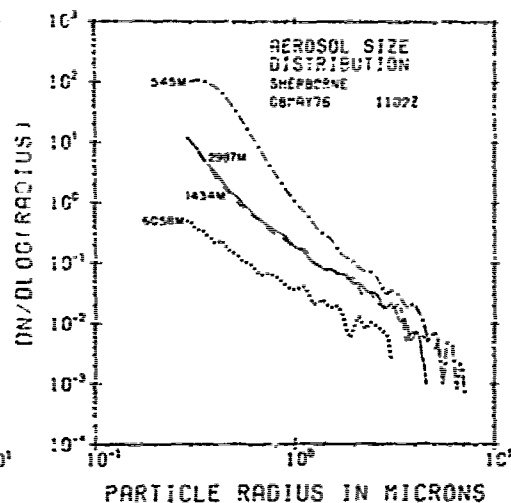
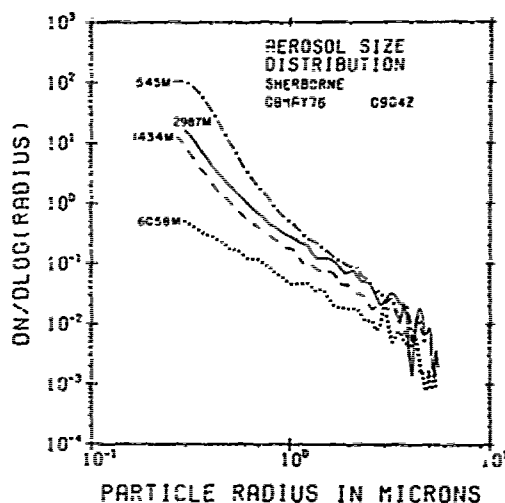
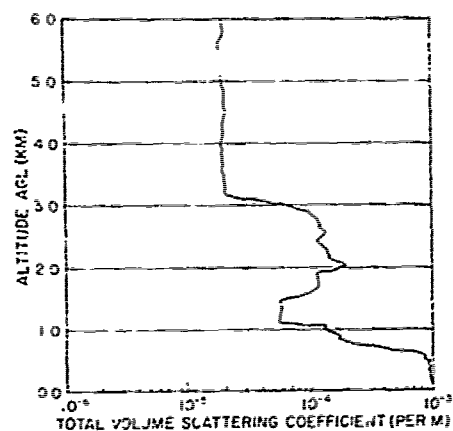
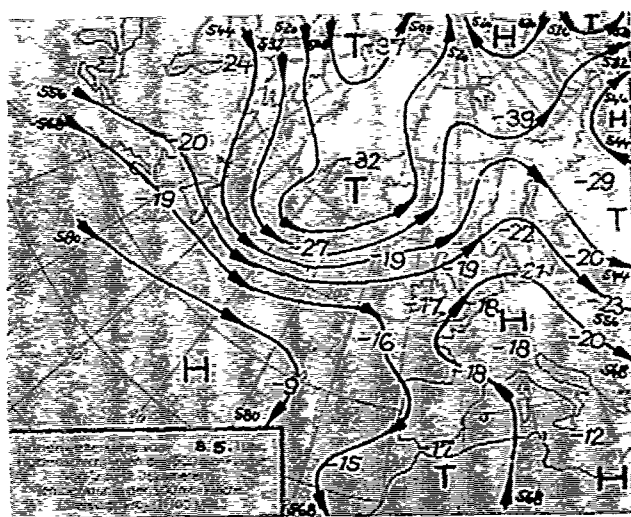
The dominating feature of the low-altitude pattern was the persistent strong ridge of high pressure from the Azores high. The air mass was maritime, but, due to the stability of the pattern, the air mass was probably quite stagnant. Under high-pressure influences at all altitudes, vertical mixing was greatly suppressed, leading to a heavy aerosol loading in the lowest layers. Likewise, in this maritime environment, the naturally occurring high-moisture levels in the low altitudes were not mixed in the vertical, creating a significant and dense surface-based haze layer.

Flight Summary

Cloud conditions on this day were no problem, with only scattered thin cirrus. The surface haze layer was found to be very dense with a top at about 1000 m; however, significant heavy haze was also observed in layers up to 3500 m. Above this, thin layers were observed up to 5500 m. Below 1400 m, the crew reported that that travel was like "flying in a bottle of milk," with visibility down to 4 km. During the data period, Yeovilton and Bournemouth both reported visibilities down to 4 km in haze.

Aerosol Data Comments

Obviously both 550 m data samples were within the surface boundary layer. However, at 1430 m and 2990 m the in-flight observer reported the aircraft to be in elevated haze layers as well, but less dense visually. Only the samples at



6060 m were taken free of visible haze layers. Horizontally, above the surface layer, the haze layers appeared uniform, but within the surface layer the haze appeared more dense to the east. This observation may or may not be significant considering the early morning sun position and the more intense scattering when looking "up sun" (towards the sun).

OPAQUE 1
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Sherborne - 10 May 1976

Time Period of Flight: 0900-1250 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0914	360	323	13.85	95-100	-3.42
0933	1450	332	3.55	20-95	-2.08
1005	2980	600	2.06	95-100	-2.00
1042	6060	600	0.14	75-100	-1.71

Second Data Set

1118	360	600	12.94	95-100	-3.32
1143	1460	562	2.05	75-95	-2.23
1209	2980	600	0.73	55-100	-1.85
1236	6060	540	0.11	55-100	-1.75

Synoptic Weather Summary

The strong high-pressure ridging aloft present for the previous week slid eastward, allowing a long trailing cold front to pass through all of England by 0200 GMT on 10 May 76. Conditions in southern England on 10 May were postfrontal with a strong northwesterly flow of "fresh" maritime polar air at all levels. Postfrontal conditions included significant cloudiness, isolated showers, and relatively good visibilities.

Air Mass Summary

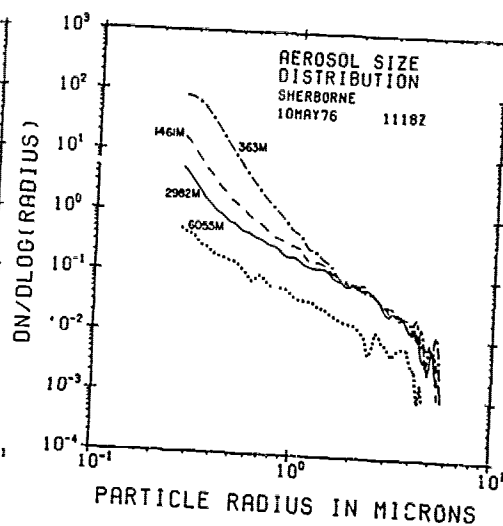
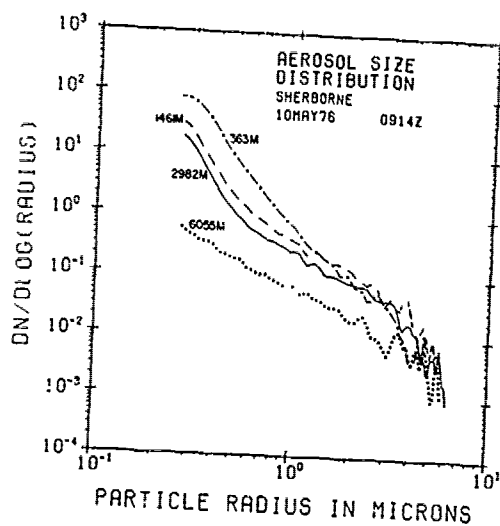
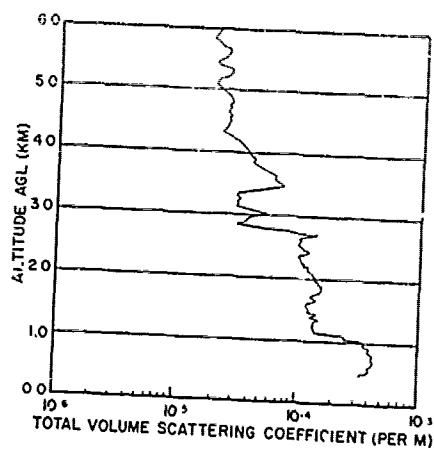
With no significant synoptic changes during the day, the Sherborne track was dominated by nearly pure maritime polar air.

Flight Summary

Upon arrival in the track area, the aircraft found overcast cirrus above 7000 m, isolated patches of altostratus at 3800 m, and isolated incipient cumulus at 600 m. The top of the low level haze layer was about 1200 m. Thin multiple layers of haze were discernible between 1700 and 4000 m. During the data period, the cirrus remained unchanged, but the cumulus coverage gradually increased to three- to five eighths with isolated towering cumulus. General cumulus tops were at 1200 m in conjunction with the top of the surface-based haze layer. The meteorological reporting station at Yeovilton, 10 km north of the track, reported similar sky conditions, visibility increasing from 7 km at 0900 GMT to 15 km at 1400 GMT. The tendency was for drying conditions with a decrease of 5°C in the dewpoint temperature with a 2 to 3°C rise in temperature.

Aerosol Data Comments

With the top of the surface-based haze layer at 1200 m, only the lowest level samples at 360 m were in the dense haze. The in-flight observer noted that the aircraft was in thin haze during the first 1460-m data sample, while at 2980 m, the aircraft was just in the top of another layer based at 2400 m. The 6060-m sample was above all haze layers. In the second series, the 1460-m sample was still in haze but with improved visibility. The 2980-m sample was in a clear layer with distinct layers of haze above and below.



OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 12 May 1976

Time Period of Flight: 0945-1118 GMT Type of Data Flight: Dual 2+2

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0954	270	600	4.70	75-85	-2.94
1016	1920	600	0.32	50-80	-1.82

Section Data Set

1044	270	600	10.52	85-90	-3.10
1114	1590	600	0.40	95-100	-2.52

Synoptic Weather Summary

The surface map shows that southern Denmark lies between two frontal systems, both of which migrated from the Atlantic over the UK and across the North Sea. The approaching system shown to the west was a maturing occlusion with wide-spread cloudiness and isolated areas of precipitation. Upper level charts show a major trough over the UK supporting the continuous eastward movement of both the system over the North Sea and the one to the west of the UK.

Air Mass Summary

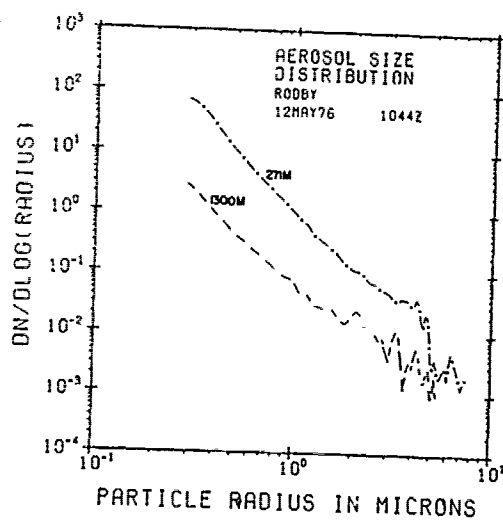
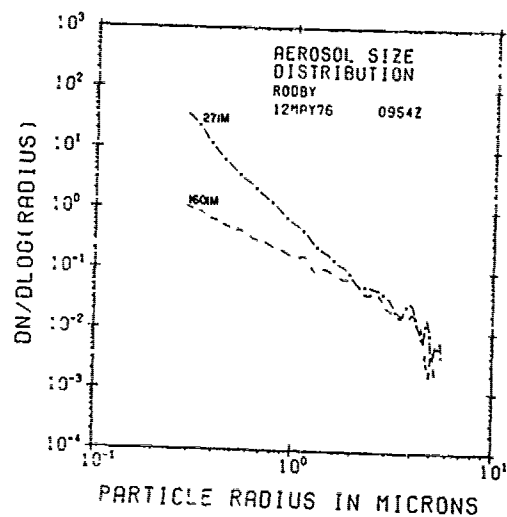
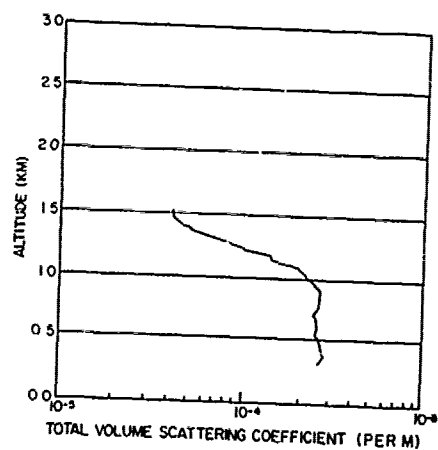
The front to the east of Rodby passed on 11 May, followed by a period of strong postfrontal winds from the northwest. This air mass was maritime polar; in conjunction with the surface ridging, apparent on the surface chart, it was stable and characterized by horizontally stratified cloudiness, mild temperatures, moist air, and good visibilities.

Flight Summary

In the track area, the aircraft found conditions of broken clouds at 2000 m with broken to overcast layers above. These were consistent throughout the flight with patches of altocumulus forming at 1700 m near the end of the data period. Significant haze was observed below 1500 m with very thin haze above. Winds at all altitudes were strong out of the northwest.

Aerosol Data Comments

During the first 270-m data pass, no significant haze was observed by the aircrew, but by the time of the second low-altitude pass, a haze layer with a top at 1500 m had been observed and was considered significant. Above 1500 m little change was noticed. Heavier haze was observed to the west both below and above 1500 m.



OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 17 May 1976

Time Period of Flight: 1000-1330 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1005	290	574	0.82	50-80	-3.43
1035	1610	600	0.20	65-75	-2.12
1054	3170	600	0.12	65-80	-1.85
1121	5810	600	0.22	35-40	-1.97

Second Data Set

1153	290	600	1.84	65-70	-3.58
1220	1610	600	0.18	15-30	-2.04
1246	3170	452	0.10	75-90	-1.90
1317	5810	600	0.22	30-45	-2.00

Synoptic Weather Summary

A deep upper level trough west of Great Britain was causing a series of frontal surfaces to pass through the Rodby area. On 16 May, a moderately strong maritime cold front passed with strong postfrontal conditions. For 17 May, the surface map shows weak high pressure dominating southern Denmark with another strong occlusion approaching from the northwest.

Air Mass Summary

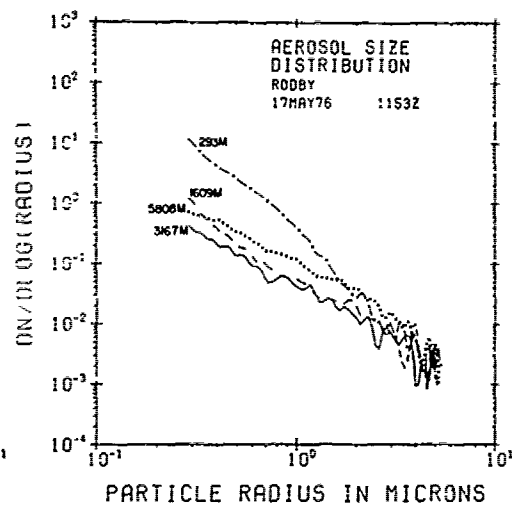
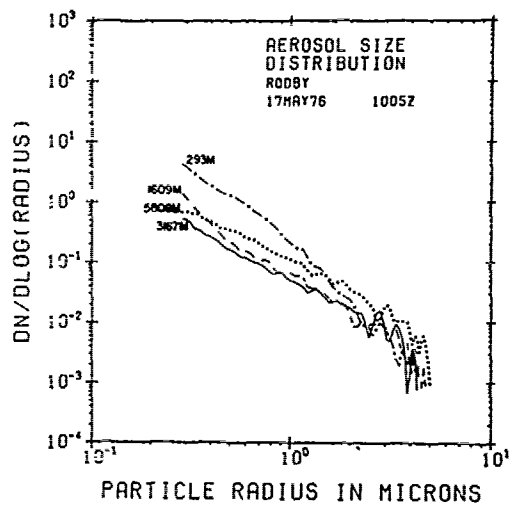
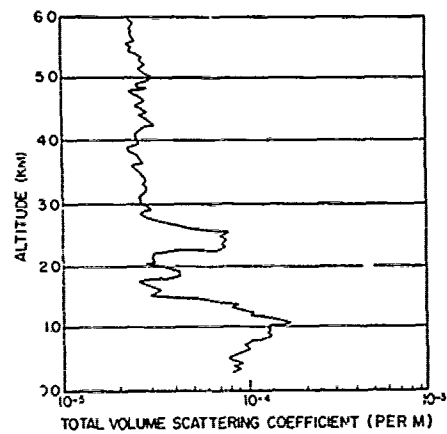
As on 12 May, the dominating air mass was a relatively fresh pool of maritime polar air which had been in dominance only a short time. This air mass was clearly maritime with little continental influence. It was moist and relatively clear.

Flight Summary

Upon arrival in the area, the aircraft found clear conditions with light haze. During the long Dual 2+4 Profile, thin cirrus clouds moved in from the west, and about one-eighth of cumulus cloud coverage developed over land areas. From low altitude, the haze appeared light, ground stations were reporting better than 20-km visibility, but from above 1500 m the low level haze appeared distinct and of moderate density. Multiple thin haze layers were observed up to 3000 m. The densest haze was observed between 1500 and 1600 m, just below the top of the most distinct haze top. A second significant haze layer was observed from 2300 to 2600 m.

Aerosol Data Comments

Correlation of observed aerosol properties to data on this day is difficult. Typical air mass conditions were exceptionally clear, making haze layers very identifiable even though not extremely dense (see total particle concentration figures in tables). Although not observed visually, there is a significant difference in the low level samples, whereas the remainder indicate a great consistency, in agreement with observations. Although there is no reason to suspect the 1153 GMT sample, perhaps it should be held suspect to some degree.



OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 25 May 1976

Time Period of Flight: 1045-1415 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1054	280	259	15.92	80-90	-3.40
1131	2110	218	1.94	70-75	-2.56
1204	3330	600	0.41	35-45	-2.50
1228	5460	378	0.44	55-60	-2.60

Second Data Set

1257	280	600	19.56	85-100	-3.39
1333	3330	600	0.43	40-60	-2.45
1359	5460	600	0.71	35-45	-2.65

Synoptic Weather Summary

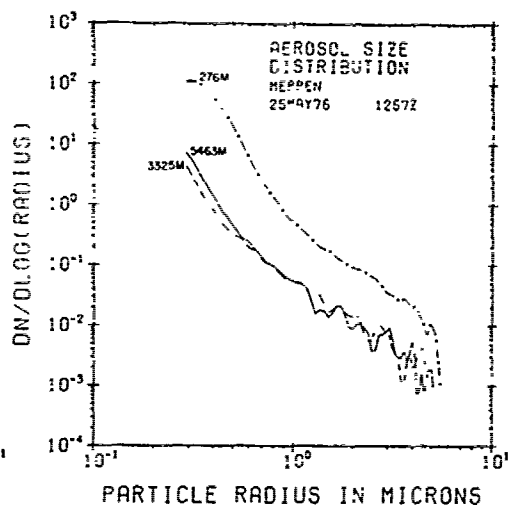
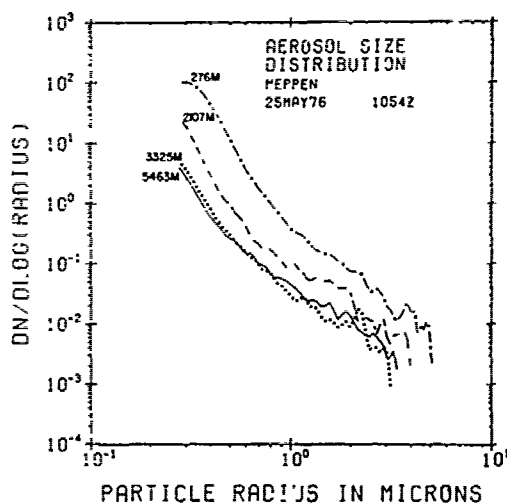
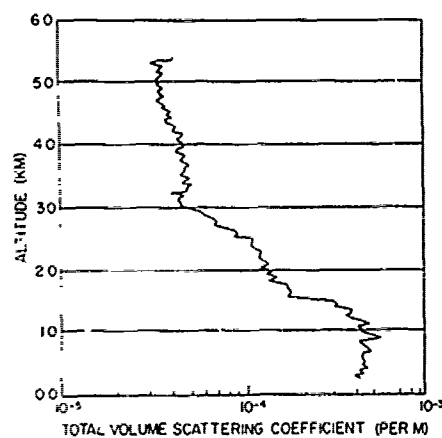
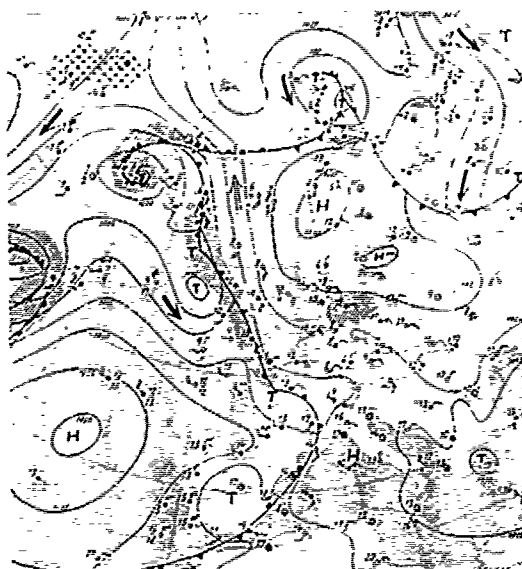
An inverted block in the upper level flow with high pressure over Norway and Sweden was forcing surface systems well to the north and stalling frontal systems over Great Britain. On 25 May 76, a well-defined frontal system extended from the east coast of Greenland to London, to Paris, and to the coast of Spain. The associated trough aloft was located west of the UK and was moving very slowly into the established ridge. At the surface, a strong surface high-pressure region over central Norway and Sweden had been dominating the air flow over northern Europe since 23 May, creating a well-defined easterly flow of relatively dry, cool air from mid-continental Asia. Above 2000 m the dominating flow ceased, but the closed circulation at 500 mb suggests continental influences may well have extended that high. During the flight period, surface winds at Meppen remained moderate out of the east with 50 to 60 percent relative humidity.

Air Mass Summary

For the previous two days, flow had been from continental source regions. Although the initial air mass was maritime polar, the long period of continental flow over northern Germany resulted in a cool dry air mass to a considerable depth. There are no indications in aircraft temperature and relative humidity data to indicate a change from continental to maritime type air mass.

Flight Summary

Upon arrival in the area at 1055 GMT, the aircrew found three-eighths of cumulus cloud coverage at about 900 m with tops at 2000 m. Visibility was estimated at 5 km in haze. During climbs to higher altitudes, no sharp haze top was identifiable—only a gradual transition from haze to clear air above 2300 m. By the end of the data period the cumulus became isolated towering cumulus with tops to 3300 m; the haze layer top became more well-defined at 2600 m. Visibility remained much the same. Cirrus coverage gradually increased from zero to three-eighths coverage. At Meppen all parameters remained relatively constant with scattered cumulus, 7 to 9 km visibility, and temperature increasing from 16 to 18°C; winds remained easterly with a relative humidity of about 50 percent.



Aerosol Data Summary

All data were taken, as desired, in clear air, free of cloud influences. Altitudes were selected to avoid levels at which cumulus would prevent a 10-minute uninterrupted data run. Data at 280 and 2110 m were within the best defined haze layers, while the 3330- and 5460-m data were taken in clear air above.

OPAQUE I
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 26 May 1976

Time Period of Flight: 0920-1100 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0934	330	578	9.29	80-85	-3.68
1004	3640	476	0.02	40-45	-4.88
1040	5440	267	0.04	45-55	-2.16

Synoptic Weather Summary

The trough at 500 mb associated with the surface frontal system over the UK on 25 May continued to dig into the bottom side of an inverted blocking pattern over Scandinavia. This allowed the well-defined surface frontal system to slide through the Meppen area the night of 25 May to a position to the east. Postfrontal flow was cool and humid out of the west to northwest from the surface of 6-km altitude. The air mass was unstable with considerable cloudiness.

Air Mass Summary

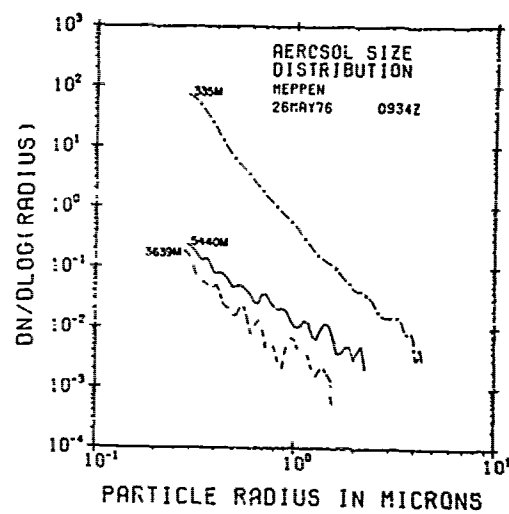
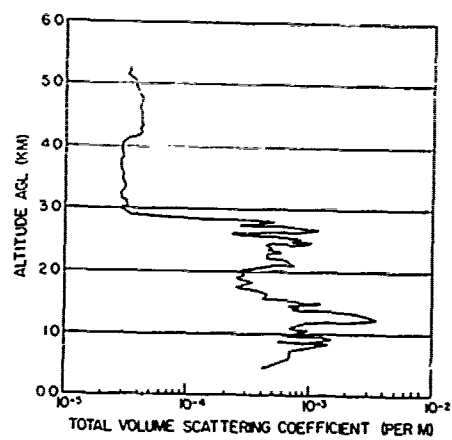
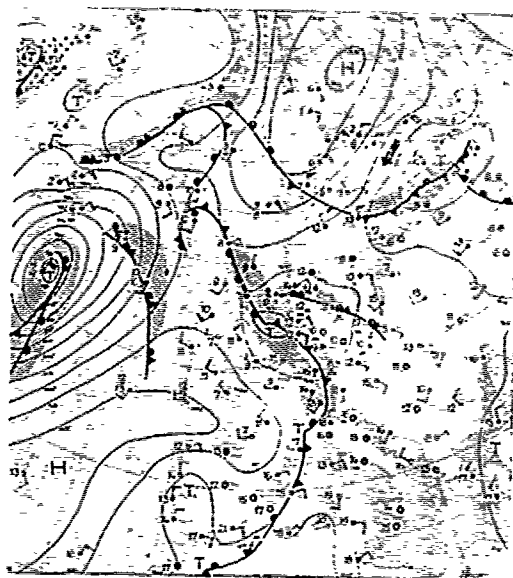
The postfrontal air mass was maritime, modified by a trajectory over the industrial areas of the northwest, including the UK. Extensive precipitation in the immediate frontal area could have had a cleansing effect below 3 km. Vertical temperature and relative humidity data indicate the frontal surface was at about 3 km. Aerosol data above 3 km could be indicative of an old continental air mass instead of a new maritime environment.

Flight Summary

At the beginning of the data mission at 330 m, four-eighths of cumulus were observed based at 800 m with clear skies above. By the start of the second data level at 3640 m, coverage of cumulus had increased to overcast with thunderstorms approaching from the southwest through northwest. Data runs were completed at 3640 and 5440 m before terminating this mission due to worsening weather conditions.

Aerosol Data Summary

In unstable maritime air mass, no well-defined haze layers were observed except that visibility below 330 m was limited to 5 km. Air above 3 km was found to be very clear.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 25 October 1976

Time Period of Flight: 1140-1640 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for r > 0.4 μm
1235	310	240	52.99	100	-4.03
1223	610	240	51.51	90-100	-3.87
1303	1510	240	0.58	74-80	-1.17
1407	6100	240	11.12	<30/cirrus fallout	-2.88

Second Data Set

1439	310	240	53.49	95-100	-3.82
1501	1510	240	0.78	65-70	-1.18
1529	3010	240	0.45	55-65	-1.08
1555	6080	240	0.13	65-70	-0.66

Synoptic Weather Summary

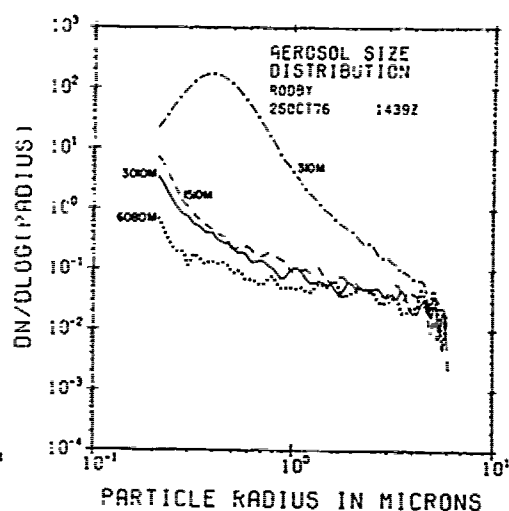
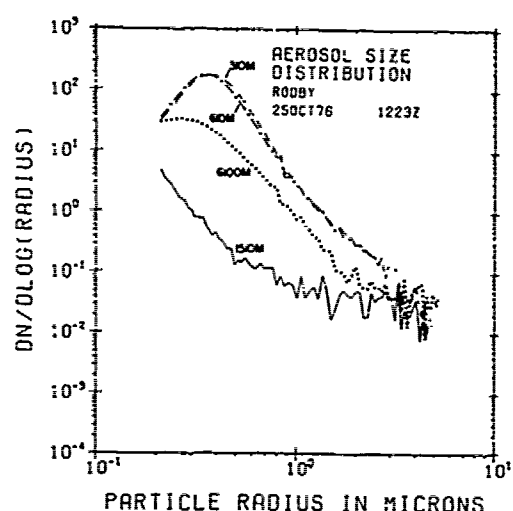
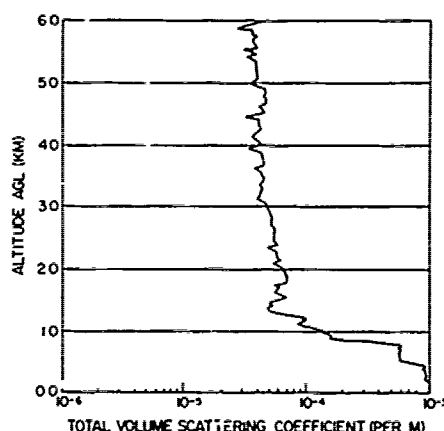
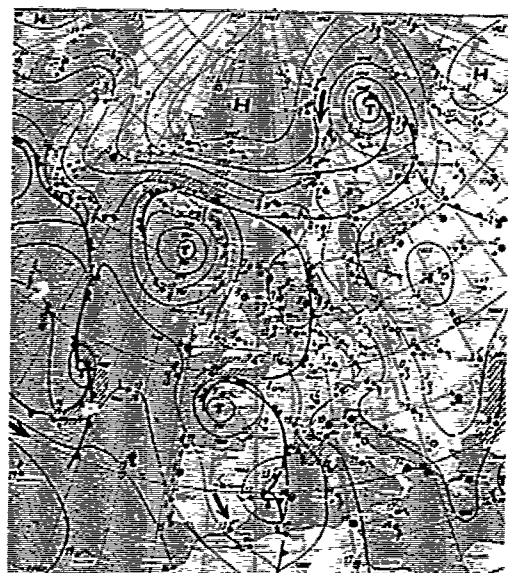
A deep trough aloft over Ireland and Spain was associated with a northwest-southeast series of low-pressure systems at the surface. A strong ridge of high pressure over Poland and Sweden and northwestward was blocking eastward migration of major systems. At the surface, high pressure over Siberia dominated flow over eastern Europe and Denmark from 23 October through this day; moderate, cool southeasterly or southerly flow persisted with widespread low-level stratus to the south and over the Baltic where water temperatures were significantly warmer than air temperatures.

Air Mass Summary

The air mass recirculating over Siberia was initially a maritime air mass migrating eastward. Stagnating conditions in the upper atmosphere caused surface high pressure to dominate for several days, allowing for a long trajectory of originally maritime air over central Siberia, southern Russia, back to eastern Europe, and Scandinavia. The net effect was that an essentially continental type air mass was dominant except for modifications induced in the lowest several hundred meters by flow over warm Baltic waters. Thus, except possibly for lowest layers, continental air appears to have dominated southern Denmark on 25 October 76.

Flight Summary

This was an excellent day in all respects. Upon arrival in the track area, the aircrew found clear skies with dense haze below 1000 m; visibility in haze was estimated at less than 4 km. South of the track, continuous stratus was observed over land areas. During the data period, cirrus clouds moved into the area from the west at about 7-km altitude, but with ice crystal fallout ("mares tails") reaching down to 6 km on isolated occasions. Isolated patches of stratus were observed starting to form over the windward sides of islands. By the end of the data period, cirrus coverage was five-eighths, with clear skies over water along the track. Over land areas, stratus coverage was broken to overcast. At the Fehmarnbelt lightship, 10 km south of the track, observations indicated only scattered cirrus all day, visibility 4 km or less, high relative humidity, and easterly to southeasterly winds of 5 to 10 knots.



Aerosol Data Comments

Data from 300 and 600 m were within the dense low-level haze layer while all other measurements were made in the remarkably clear air aloft. No haze of any kind was visible above the surface-based layer. At 6-km altitude, isolated patches of ice crystal fallout from cirrus were penetrated during the 1407 GMT data run, accounting for the very strange numbers contained therein. The 1555 GMT data for 6 km were taken without cirrus particle influences.

OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 26 October 1976

Time Period of Flight: 1010-1340 GMT Type of Data Flight: V-PRO

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1203	310	120	52.40	100	-3.95
1212	560	60	45.70	100	-4.02
1257	910	60	19.37	100	-3.17
1239	5180	60	0.21	70-75	-0.80

Synoptic Weather Summary

The very strong ridging over western Russia continued from 25 Oct 76. All surface low-pressure systems were being stalled in their eastward migration by the strong upper level ridging action and were forced to move north-northwestward from France to the UK to Iceland. The strong surface high-pressure center north of the Black Sea continued to dominate circulation over eastern Europe and Scandinavia with cold dry air. Winds over this region were generally easterly at 10 to 15 knots.

Air Mass Summary

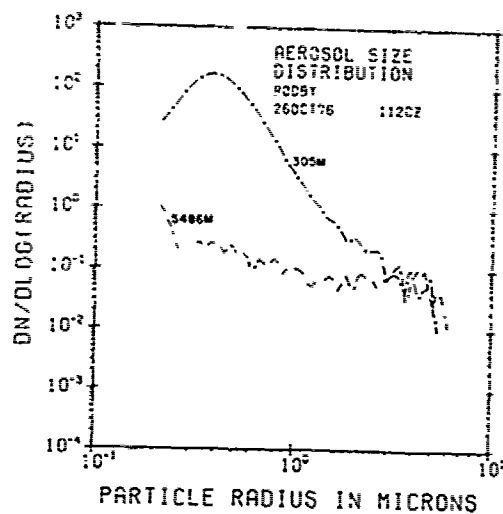
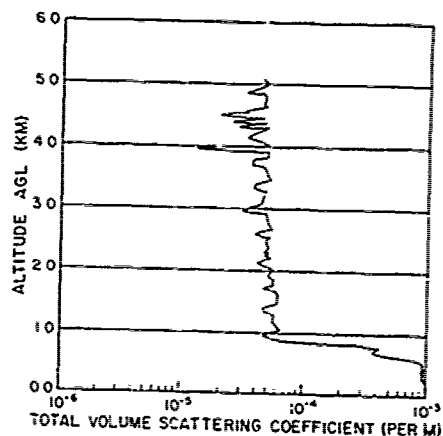
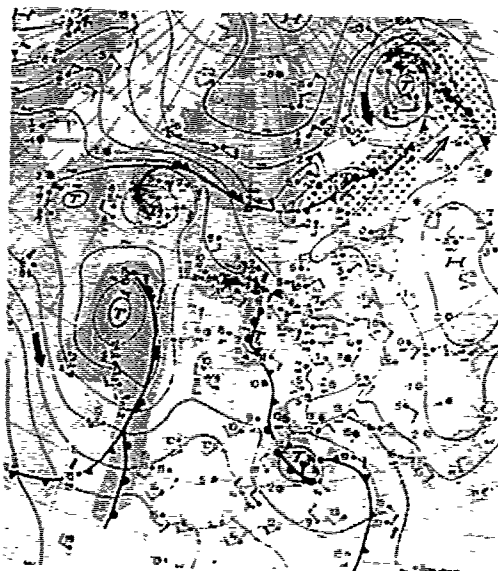
Below 1 km, continental polar air dominated, but due to the warm water of the Baltic and strong winds, the lowest levels were rapidly saturated with water vapor, creating a maritime modified continental air mass below 500 m. Continental air dominated from 500 to 1000 m but the air above was probably aged maritime air modified by movement over the high mountains of southern Europe.

Flight Summary

Upon arrival in the track area, the aircrew found overcast low-level stratus with a single large hole in the overcast over the eastern end of the track. Tops of the stratus deck were about 900 m, which also marked the top of the dense haze layer. The visibility in haze over the east end of the flight track was estimated at 4 km. Skies were exceedingly clear above the cloud top. The conditions remained approximately the same through the data period as a series of V-PRO's were flown with limited aerosol data. At Fehmarnbelt lightship, just south of the track, conditions were broken to overcast stratus, 2- to 4-km visibility in haze or thin fog, high relative humidity, and southeasterly winds at 15 to 20 knots.

Aerosol Data Comments

Due to the data profile, the aerosol data sequence was not strictly low altitude to higher altitudes. The 310- and 560-m samples were taken in the heavy haze over the eastern end of the track, while the 910-m sample was taken after ascent, descent, and level off just above the cloud deck. Visually, at 910 m, the aircraft was in clear air above stratus and dense haze.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 1 November 1976

Time Period of Flight: 1030-1320

Type of Data Flight: Dual 2+2

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for r > 0.4 μm
1124	460	240	40.14	90-95	-4.10
1144	1170	240	10.25	95-100	-3.56

Synoptic Weather Summary

A deep upper level trough over central Europe and a series of short wavelength troughs moving in the upper westerly air stream were associated with deep migrating low-pressure systems at the surface. On 1 November, the surface chart shows the Meppen area between two major systems; one, moving northeast, was located over the eastern Baltic Sea with a front reaching into Russia and the Balkans, while the second major system, a very deep low center, was located south of Iceland with a strong frontal surface over the British Isles and west of France. By noon on 1 November, the frontal system lay on a line from London to northwest France proceeding eastward at 25 to 30 knots. During the night of 31 October, several minor troughs passed through the Meppen area ahead of the major front, causing widespread cloudiness and showers.

Air Mass Summary

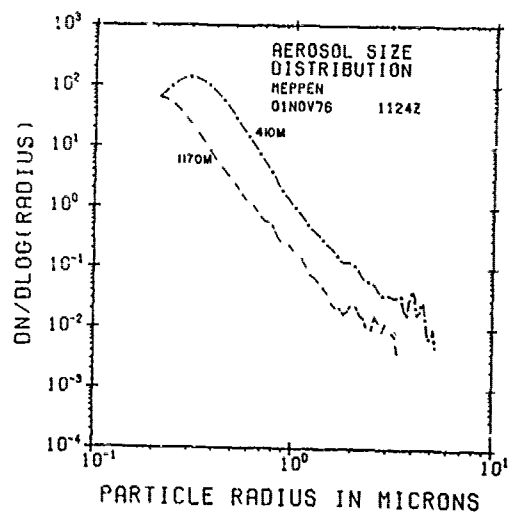
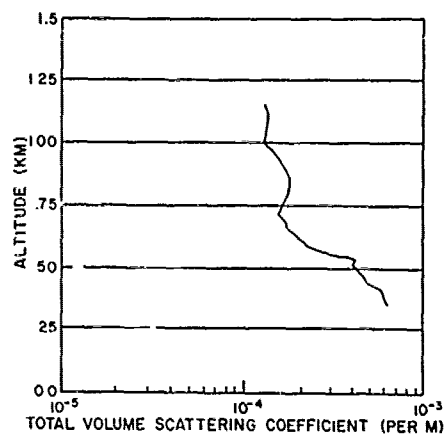
The air mass over Meppen during the data period was maritime, but not necessarily air fresh off the north Atlantic. This maritime air mass should be considered prefrontal air with a trajectory from the Atlantic into southern Europe and hence northward ahead of the frontal surface. Thus it was a maritime air strongly modified by continental influences.

Flight Summary

Upon arrival in the track area, the aircrew found unstable and rapidly changing cloud conditions. At the beginning, cloud conditions were observed to be variable between broken multilayered clouds above 1500 m and clear below 6 km. Visibility below clouds was about 8 km in haze. Haze was continuous up to cloud base. During the data period, cloud conditions gradually worsened, with increased cloudiness above 1500 m plus scattered stratus fractus at 600 m. A Dual 2+2 Profile at 460 and 1170 m was flown due to weather limitations. Surface reports from the west end of the track area reflected similar cloud and visibility conditions.

Aerosol Data Comments

Aerosol data at 460 m and 1170 m were taken only during the first cycle of the Dual 2+2 profile. Data were taken in clear air below the ceiling deck at 1500 m and provides a good data set for a prefrontal atmosphere below an overcast over the North German Plain.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 2 November 1976

Time Period of Flight: 0951-1151 GMT Type of Data Flight: V-PRO

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1037	310	240	25.46	100	-3.44
1046	1520	60	2.59	100	-2.90

Second Data Set

1120	340	240	29.18	100	-3.50
1111	1520	60	3.15	100	-3.45

Synoptic Weather Summary

A deep upper level trough continued to dominate over the west coast of Europe with a blocking ridge downstream, north of Murmansk. A very deep low was centered south of Iceland and was essentially stationary in a vertical stack, with an upper level closed as part of the dominating upper level trough. A strong frontal system extended to Norway, Denmark, and Southwestward over Germany and France. Numerous weak postfrontal troughs migrating in the cyclonic flow were associated with areas of shifting winds and widespread cloudiness and showers, alternating with areas of relatively clear skies. All were fast moving systems and resulted in rapidly changing conditions at any given point. At Meppen, the frontal system passed during the night, but a secondary trough was approaching during the data period.

Air Mass Summary

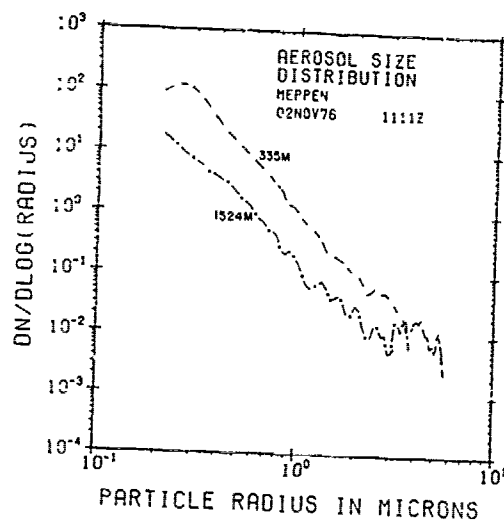
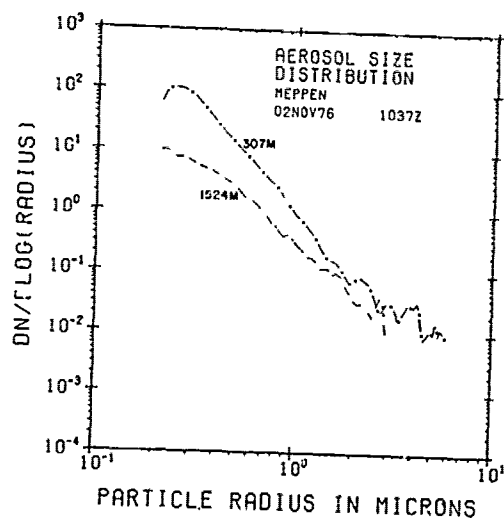
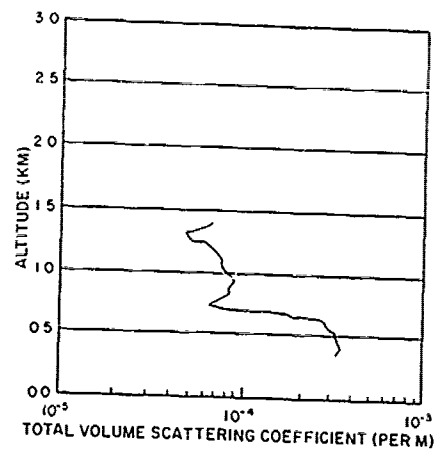
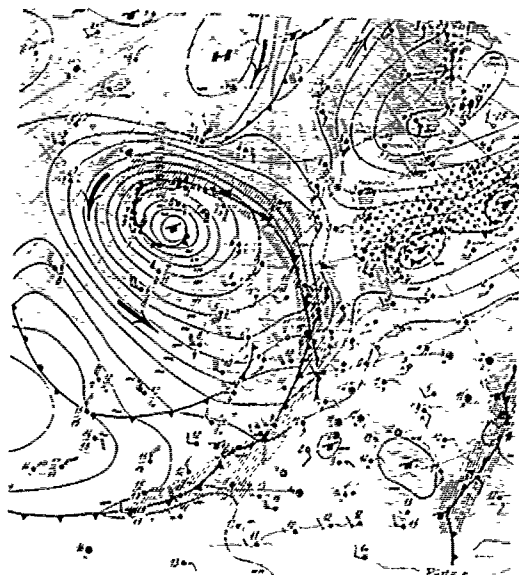
The air mass was distinctly postfrontal maritime polar air, with some continental modification from its rapid movement over populated regions to the west.

Flight Summary

Upon arrival in the track area, the aircrew found overcast skies with bases variable from 1500 to 2500 m and scattered stratus fractus below. Subcloud base visibilities were estimated at 15 to 20 km. Lower and more dense clouds and apparent showers were visible to the west. During the flight period, the ceiling at 1500 m became more dense with more widespread clouds at 600 m. Due to the unstable weather conditions, a series of vertical profiles from 300 to 1500 m were flown with aerosol data taken at 300 m and just below cloud base at 1520 m. Surface stations in the area reported visibilities of 10 to 20 km and southwesterly winds at 10 to 15 knots. Southwesterly winds were the result of an approaching secondary trough.

Aerosol Data Comments

Combined with prefrontal data from the previous flight, 1 November, this data set provides a good example of the type of changes that can occur in prefrontal vs postfrontal air masses over Europe, even when the initial air masses were, in all probability, very similar.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 18 November 1976

Time Period of Flight: 1027-1405 GMT Type of Data Flight: Dual 2+2

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1140	270	240	8.76	90-95	-4.20
1207	910	720	2.09	95-100	-4.00

Second Data Set

1229	270	240	21.19	95-100	-4.23
1255	910	240	14.28	95-100	-4.72

Synoptic Weather Summary

The period including 18 November 76 at Meppen was characterized by frontal passages about every second day. The upper level pattern showed a strong trough over eastern and southeastern Europe with strong northwesterly flow over western Europe, in association with a developing ridge along 15°W longitude. The surface map shows a deep low north of Scandinavia, an active but filling migrating low over Ireland, and high pressure dominating southern Sweden, Denmark, and northern Germany. Cloud patterns over the Baltic Sea were variable with areas of clear skies and areas of considerable cloudiness. There were no impending significant features to change the pattern through the day.

Air Mass Summary

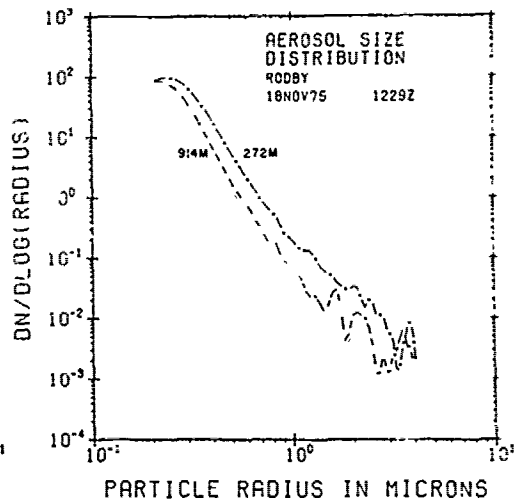
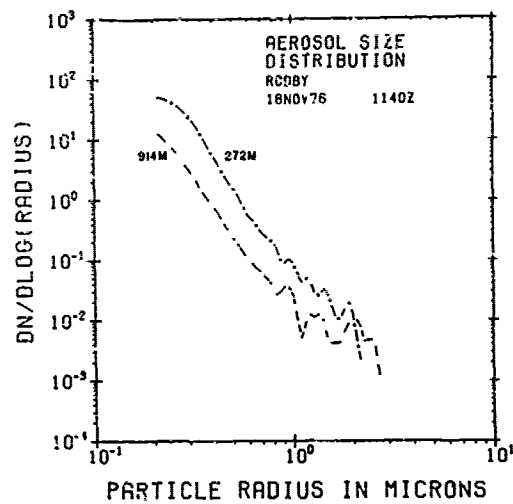
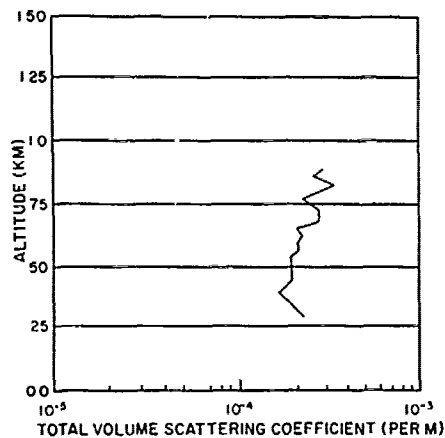
The dominant air mass was a relatively fresh maritime air mass which had moved into Scandinavia from the North Atlantic within the previous 48 hours. With a short overland trajectory, the air mass was still predominantly maritime.

Flight Summary

Upon arrival in the track area, the aircrew found a predominant overcast at 1000 m with good visibility below. Due to stratus over the Fehmarnbelt, the track was changed to a north-south track over water approximately perpendicular to the west end of the track and approximately parallel to Langeland Island. Visibility was good, with denser haze on the south end of the track than on the north end. During the data period, the Fehmarnbelt lightship reported similar cloud conditions, 10- to 20-km visibility and westerly to northwesterly winds at 6 knots.

Aerosol Data Comments

The two sets of data at 270 and 910 m are at the lowest altitude and just below cloudbase, respectively. The first data set was taken primarily on the north end of the track, while the second data set starting at 1229 GMT document conditions in the denser haze at the south end of the track.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 19 November 1976

Time Period of Flight: 1023-1510 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1140	320	240	12.08	70-80	-3.26
1216	2000	240	0.80	25-30	-3.43
1239	4440	240	0.13	95-100	-1.92

Second Data Set

1321	320	240	9.81	75-80	-3.24
1343	2000	240	1.22	40-45	-3.81
1404	4440	240	0.17	100	-1.54

Synoptic Weather Summary

This was a postfrontal situation. In the early morning, the remains of the migrating low over Great Britain on 18 November pushed through the track area, leaving the track under the circulation domination of a strong, vertically stacked, high-pressure center over Great Britain. Upper level flow was strong north-westerly with no features threatening impending changes in the track area.

Air Mass Summary

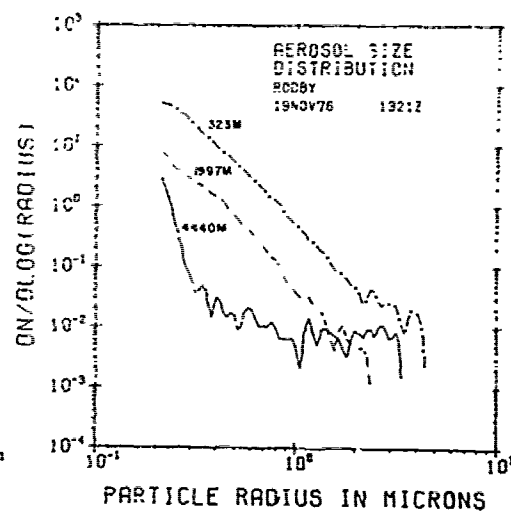
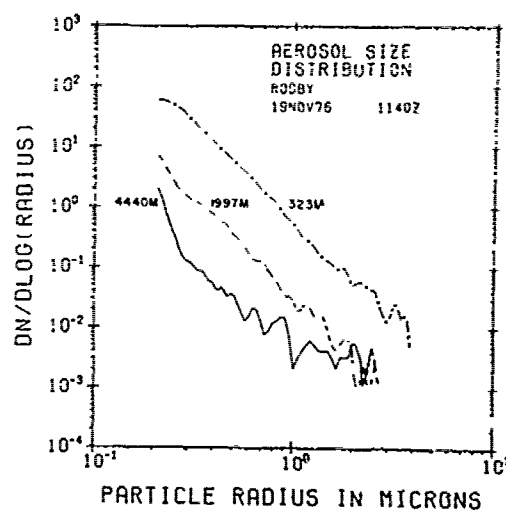
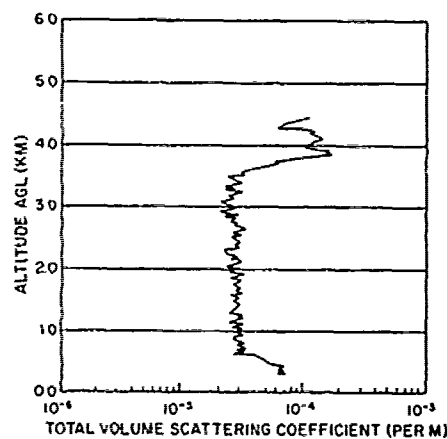
This day represented a postfrontal maritime polar air mass with little, if any, continental influence. Air and water temperatures were similar. The air mass was stable and horizontally homogeneous.

Flight Summary

Sky conditions during the data period were variable with three- to seven-eighths coverage at or above 5-km altitude, but clear below. Visibility was excellent, 20 to 30 km, with light haze below 300 m. Conditions were stable throughout the flight.

Aerosol Data Comments

The 320 m data samples were taken just in the top of the surface-based haze layer, and may represent the integration over a series of variations associated with being near the top of the layer.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 22 November 1976

Time Period of Flight: 0905-1110 GMT Type of Data Flight: WX ABORT

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1017	340	240	4.25	100	-2.87

Synoptic Weather Summary

Upper level charts show a long wave trough over eastern Europe and the Mediterranean with a long wave ridge over the Atlantic along 20°W longitude. Strong gradient flow on the northwesterly air stream existed over Great Britain and the North Sea. The 0100 GMT surface chart shows a strong, rapidly moving cold front was driving south out of the North Sea into northern Germany. This frontal system passed the Meppen area in the early morning of 22 November, resulting in strong northwest flow over the region with rain and showers in the postfrontal air mass.

Air Mass Summary

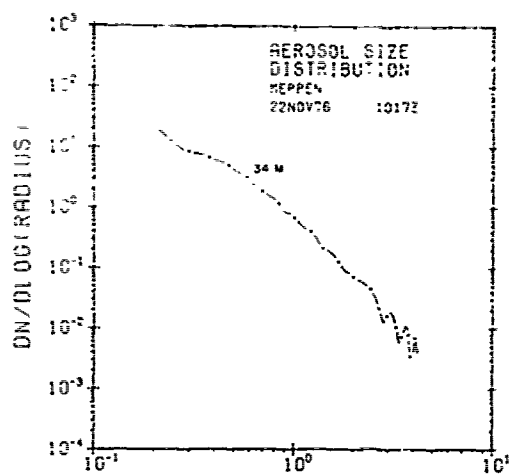
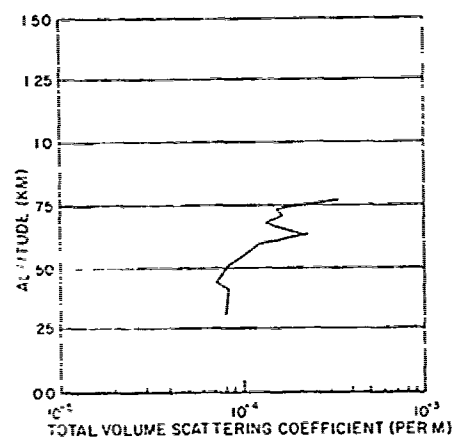
On this day the air mass in the track area was strictly maritime polar. It was cold and unstable.

Flight Summary

Weather abort after a single pass at 340 m.

Aerosol Data Comments

Although taken only at one level, this data sample should be indicative of the immediate cold postfrontal aerosol characteristics of a winter season maritime polar air mass.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 23 November 1976

Time Period of Flight: 1107-1110 GMT Type of Data Flight: V-PRO

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1321	310	60	3.27	90-95	-2.56
1333	910	60	2.44	90-95	-2.48
1343	2440	240	0.51	55-60	-1.65
1256	4290	184	0.71	75-80	-3.00

Synoptic Weather Summary

The upper air pattern, persistent for the preceding 24 hours with strong northwest flow over all of western Europe, was dominated by a deep trough over eastern Europe and the Adriatic with a long wave ridge over the mid-Atlantic. The surface chart shows a strong front, which had pushed southward over Germany during the previous 24 hours, dissipating along the Alps. A strong low-level gradient between the high-pressure center west of the UK and the deep low north of Siberia continued to maintain a strong northwest flow over northern Germany. Conditions were still postfrontal in the Meppen area with a highly unstable air mass, which resulted in widespread cloudiness and shower activity.

Air Mass Summary

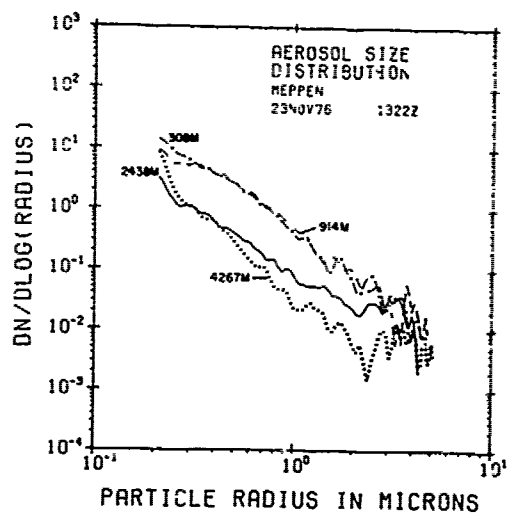
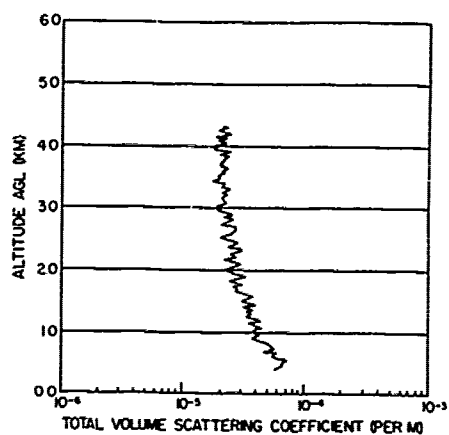
The dominant air mass was maritime polar air direct from the Norwegian Sea with little or no continental influence.

Flight Summary

Widespread cumulus development prevented long straight and level flights at any altitude. Rain and snow showers were scattered with little cloud coverage in between; vertical profile ascents and descents were made without having to pass close to showers. Short aerosol data runs were made in clear areas. No identifiable haze layering was observed, but in sunlit areas a surprising haze density was observed; this was perhaps only a visual effect, as visibility was not limited. Surface reports during the data period indicated variable cloud coverage, showers, 20- to 30-km visibility and northwest winds at 6 to 12 knots.

Aerosol Data Comments

The data are representative of postfrontal conditions for a winter type maritime air mass penetration into northern Germany without influences from upstream urban areas; for example, the Netherlands to the west, and the UK to the northwest.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 2 December 1976

Time Period of Flight: 1117-1447 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for r > 0.4 μm
1155	420	120	5.36	80-85	-3.01
1221	800	240	4.57	100	-2.84
1243	2000	240	0.21	60-65	-1.25
1308	4400	240	0.24	80-90	-1.62

Synoptic Weather Summary

At upper levels, a strong ridge over the mid-Atlantic, in conjunction with a deep trough from Norway to Scandinavia, caused strong northwest winds over all of western Europe. The surface map shows a deep low centered over Germany, with a strong frontal system extending southwestward over Corsica and into Spain. The strong gradient west of the UK caused strong northwest flow over western France. Within this flow, the air mass was unstable, resulting in occasional widespread cloudiness and lines of shower activity.

Air Mass Summary

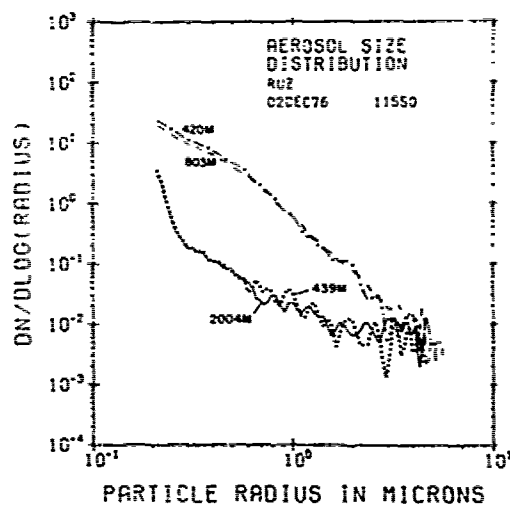
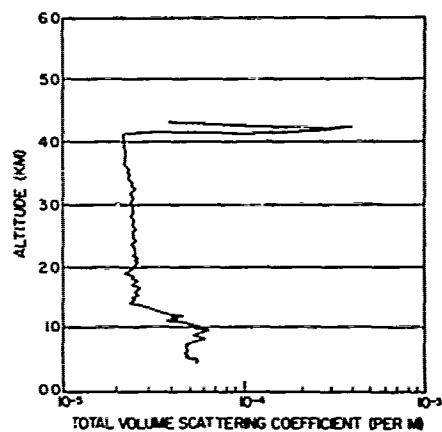
In the Bruz track area, the air on 2 December was postfrontal maritime polar with little trajectory over populated land areas.

Flight Summary

Upon arrival in the track area the aircrew found one-eighth of coverage by stratocumulus clouds based at 850 m. Visibility was excellent in very light haze near the surface with very clear air above. During the data period, cloud coverage gradually increased west to east. Flight tracks were slid east, with intensifying cumulus shower activity moving in from the west. A full Dual 2+4 Profile was completed, staying in front of the convergence line as it moved east. Aerosol data were taken only during the first cycle of the Dual 2+4 Cycle. The surface reporting station at Rennes, 6 km north of the track, reported during this period increasing cloudiness, visibility 10 km or more, and westerly winds at 15 knots.

Aerosol Data Comments

The 420 and 800 m data runs were made within the surface-based haze layer which displayed little vertical structure; it was thin throughout.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 3 December 1976

Time Period of Flight: 0945-1318 GMT Type of Data Flight: Dual 2+2/2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1017	410	240	3.15	100	-2.84
1054	1360	240	1.25	95-100	-2.70

Second Data Set

1115	410	240	3.90	100	-2.71
1157	1360	60	0.75	95-100	-2.57
1214	2570	480	0.23	85-90	-2.49

Synoptic Weather Summary

The deep surface low-pressure center that was over Germany 24 hours earlier started filling gradually, drifting northeastward to a position over the Baltic on 3 December. This low was nearly vertically stacked to a closed low over the North Sea, with a trough axis extending southeastward into the Balkans. Air flow over western Europe was generally westerly, with minor waves moving rapidly into the major trough. In consonance with waves in the upper air stream, a series of minor troughs were rotating about the still significant low-pressure center over the Baltic Sea, with a major trough over Iceland, extending to the southwest and moving southward. In the Bruz track area, minor waves created variable cloud conditions between lines of convergence. A moderately strong pressure gradient maintained strong westerly to northwesterly flow.

Air Mass Summary

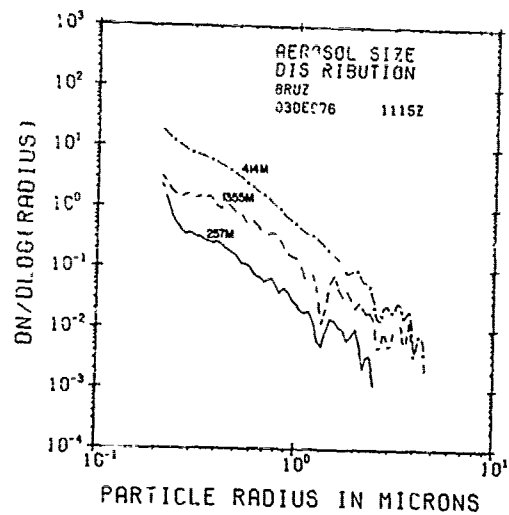
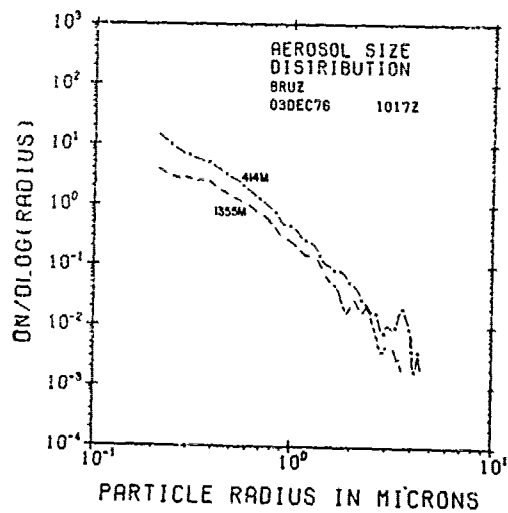
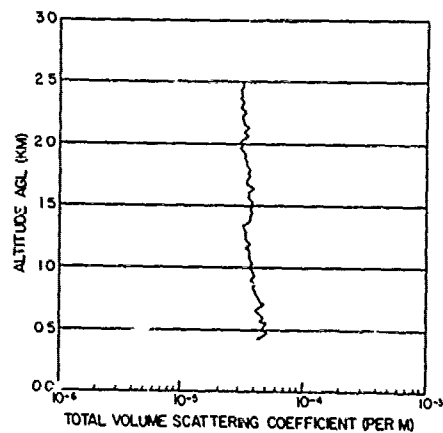
Air mass conditions show little change from 2 December. The air mass was maritime polar with little trajectory or time over land or urban areas. Air mass was moist and unstable.

Flight Summary

Upon arrival in the track area, conditions found by the aircrew were scattered to broken stratocumulus at 650 m with a higher cirrostratus overcast. During the data period, cloud conditions were highly variable in space, preventing a full profile mission. Haze conditions were observed to reflect a deeply mixed boundary layer with no marked discontinuity in haze density with height below the highest altitude flown (2570 m). By the end of the period, data runs were completed twice at 410 and 1360 m with a final single run at 2570 m. Observations at Rennes reflected broken stratocumulus coverage with cirrostratus above, 12-km visibility, and variable southwest winds at 6 to 8 knots.

Aerosol Data Summary

All data were taken in clear air away from clouds. With surface southwest winds, it is likely these data were taken in advance of an approaching trough, probably causing the low-level air mass to experience a slightly longer overland trajectory than the day before.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 4 December 1976

Time Period of Flight: 0950-1330 GMT

Type of Data Flight: V-PRO

Significant Flight Data

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1031	480	240	2.07	85-90	-3.47
1034	480	240	1.24	85-90	-3.98
1037	480	182	1.71	85-90	-3.43

Synoptic Weather Summary

In the previous 24 hours, the major trough over the North Sea experienced significant deepening in the southwest quadrant. On 4 December, the deep trough consisted of a closed low over Denmark with a trough axis to the southwest. In conjunction with the trough intensification aloft, the broad surface low extending from Ireland to the Baltic on 3 December became better defined, with a single deep center over Oslo and with the major occluded frontal system extending to the east. On its west side, a series of weak waves or troughs continued to rotate about the low, but with major activity and pressure gradient to the southwest of the track area. Conditions over northwest France were basically a continuation of 3 December, with an unstable air mass and weak lines of convergence moving through with highly variable cloudiness.

Air Mass Summary

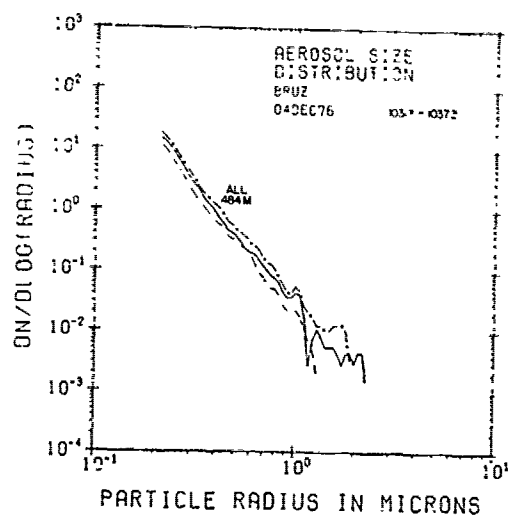
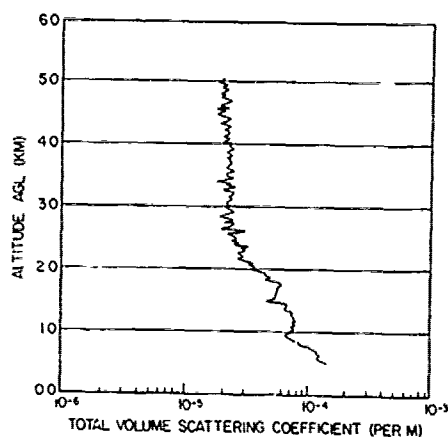
Air mass continues as maritime polar with little continental influence.

Flight Summary

In the track area, overcast cirrus and highly variable coverage below prevented consistent straight and level data runs. A series of vertical profiles were taken with aerosol data taken only at lowest altitude.

Aerosol Data Comments

None.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 5 December 1976

Time Period of Flight: 1020-1455 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1108	890	240	4.10	55-60	-3.15
1138	2110	133	0.25	20-25	-4.36
1202	5180	240	0.22	30-35	-3.72

Second Data Set

1241	410	240	10.50	70-75	-3.06
1306	890	240	3.13	55-60	-3.22
1336	2110	240	0.28	20-25	-3.00
1403	5180	240	0.11	30-35	-11.93

Synoptic Weather Summary

Upper level charts show that the closed low over Denmark on 4 December drifted to the northwest to a position north of Bergen, Norway. A second major trough was shown southwest from Iceland moving steadily eastward. An area of weak ridging between these major troughs was located west of France and Great Britain, resulting in moderate northwesterly flow over the track area. The surface chart shows a major occlusion well to the west. Weak surface ridging dominated northwest France with general conditions of few clouds other than high cirrus.

Air Mass Summary

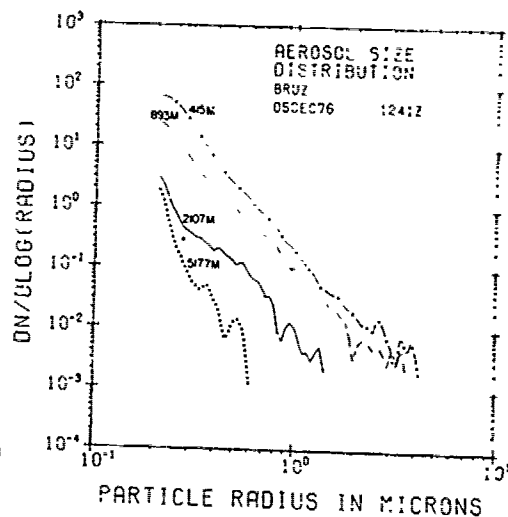
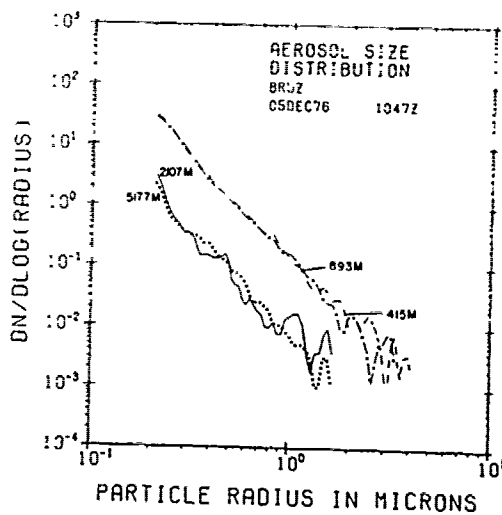
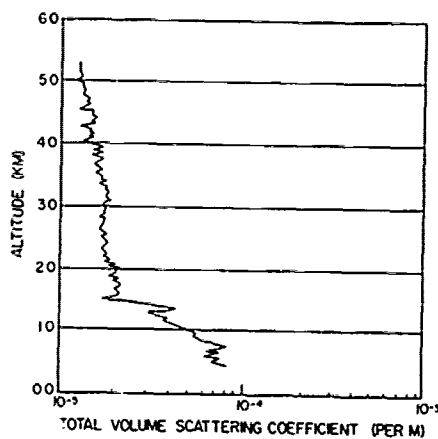
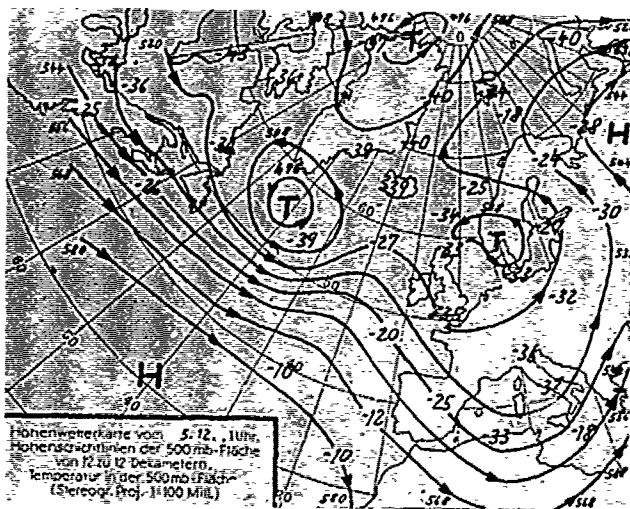
The dominant air mass remains maritime polar with a slower passage and longer residence time over continental areas.

Flight Summary

During the data period, cloud coverage gradually increased with no significant changes in general haze conditions. Initially, only scattered cirrus influenced the flight track, but by the start of the second cycle, scattered cumulus along the track caused minor modifications in flight path to avoid cloud influences. Cumulus appeared to form only along the flight track with bases at 890 m; the track was simply slid to one side. Light surface-based haze was observed with a top at about 1200 m. Distinctly separate layers above were observed and estimated at 1500 and 2000 m. At Rennes, 10 km north of the track, visibilities were reported between 11 and 35 km; winds were southwesterly at 4 to 6 knots.

Aerosol Data Comments

In comparison to previous days' measurements, the 410-m data at 1241 GMT apparently reflect effects of longer overland residence of the dominant air mass. Data at 410 m during the first cycle were unreliable due to a calibration error at the start of the data run. The 890-m data were taken at a level visually just below the top of the surface haze layer.



OPAQUE II
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 6 December 1976

Time Period of Flight: 1130-1530 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for r > 0.4 μm
1155	430	240	5.12	Unkn	-3.04
1136	1050	240	5.01	Unkn	-3.07
1231	1400	240	0.46	Unkn	-2.57
1254	3850	240	0.16	Unkn	-2.36

Second Data Set

1329	430	240	5.08	Unkn	-2.96
1354	1400	240	0.94	Unkn	-2.64
1421	3850	240	0.18	Unkn	-2.27

Synoptic Weather Summary

Within the previous 24 hours, the major long wave trough over the mid-Atlantic pushed rapidly over Ireland with a trough axis towards the south. This system was maturing rapidly and was vertically stacked to a very deep surface low-pressure center just northwest of Ireland. The extensive strong gradient field about this storm center dominated all of Europe from Poland westward. The major occlusion from this storm is shown to have pushed through Great Britain and the Bruz track regions. Postfrontal conditions with weak lines of instability dominated north-western France, causing lines of showers and widely variable and rapidly changing cloud conditions and weather.

Air Mass Summary

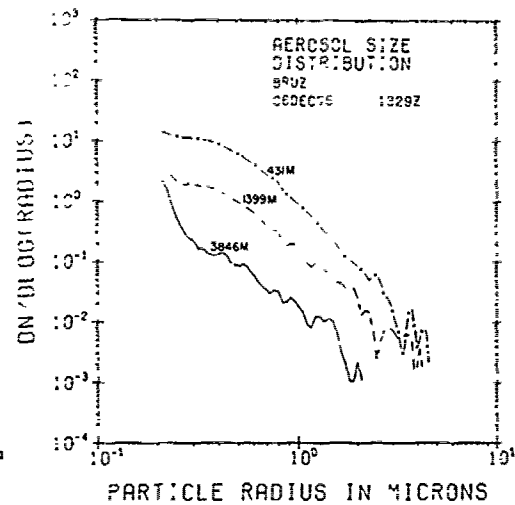
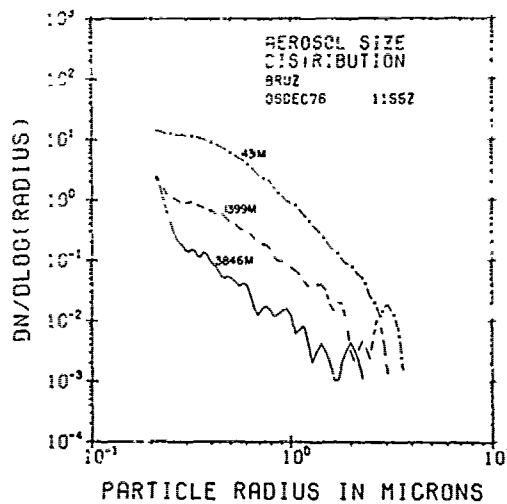
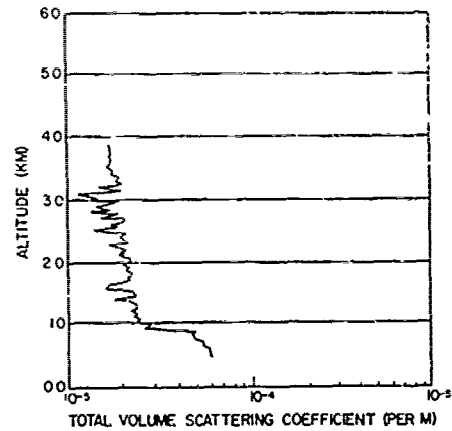
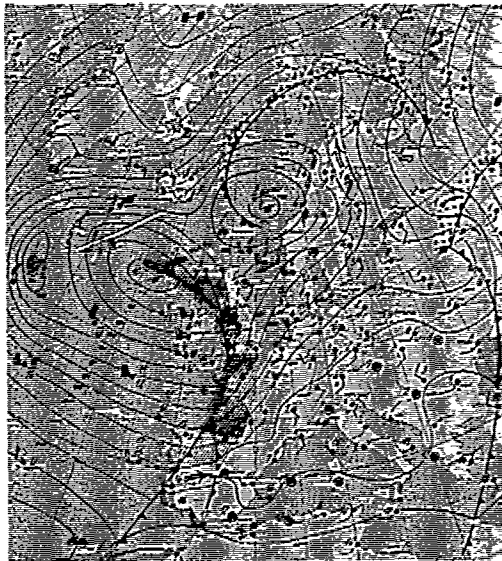
The airmass throughout most of northern France was fresh maritime air pulled in rapidly from the mid-Atlantic. Air mass was unstable moist and probably typically postfrontal for the area.

Flight Summary

Upon arrival in the track area, the aircrew found a line of thundershowers moving through. After starting one data set, the measurement cycle was restarted under more favorable conditions as the shower line moved out of the area. At the start of the second data sequence, sky conditions were reported as scattered cumulus and altostratus with light to moderate haze. The inflight observer thought haze was surprisingly dense for a postfrontal condition in a strictly maritime air mass. During the data period, cloud coverage was highly variable from nearly clear to nearly overcast stratocumulus and cirrus. A well-defined surface haze layer was observed initially reaching to 1200 m, but by 1320 GMT the layer had been compressed to 1000 m top. No discernible elevated haze layers were observed. During the data period from 1200 GMT on, Rennes, 10 km north of the track, reported scattered clouds below 6 km, visibilities of 10 to 18 km, and wind directions variable from south to southwest at 12 to 20 knots with gusts to 35 knots.

Aerosol Data Comments

The one data set of 1050 m was taken during the first data cycle attempt. Being close in time and space to the restart time, it is presented here to provide a data set just below the top of the observed haze layer. The Dual 2+3 Profile was



necessary due to fuel consumed during the abortive first data acquisition attempt. All data were taken free of cloud influences and should be comparable to other fresh maritime air mass data sets.

OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 4 July 1977

Time Period of Flight: 1042-1508 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1128	430	240	23.10	70-75	-2.42
1204	1680	240	17.66	75-90	-2.66
1223	3200	209	2.90	80-90	-1.59

Second Data Set

1317	460	219	30.13	60-70	-2.68
1340	1070	240	24.10	65-85	-2.89
1414	3200	240	3.75	80-90	-1.80

Synoptic Weather Summary

The upper level pattern for 0000 GMT 4 July 1977 shows a deep closed stationary low at 500 mb just south of Iceland with a second deep trough over the Baltic Sea and Russia. The 500-mb height field was weak over all of western Europe, with a tendency towards weak ridging over the UK and weak troughing over Spain. The surface map for this day shows a weak pressure pattern over Europe with a weak trough over central France. A well-defined frontal system west of the British Isles extended towards the southwest. Widespread cloudiness was indicated over central and southern France and northern Spain.

Air Mass Summary

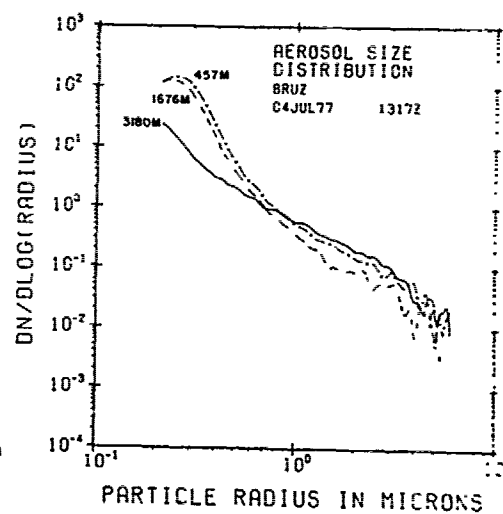
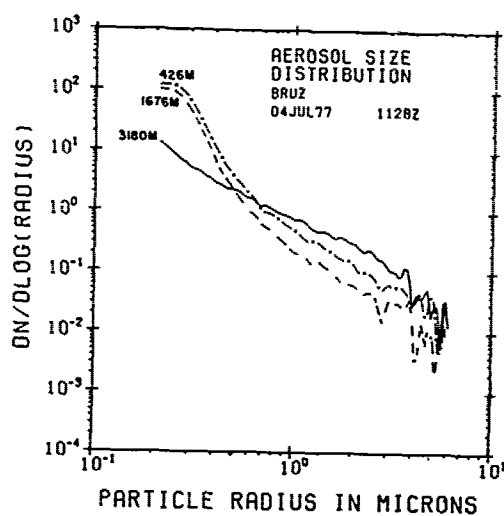
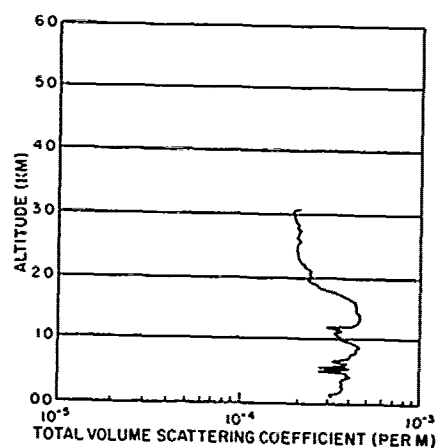
For the previous three days the near surface circulation over northern France was weak easterly. Though originally maritime, the dominant air mass on 4 July must be considered to be weakly maritime with very strong continental modifications resulting in increased haze density and depth.

Flight Summary

Upon arrival in the track area, the aircrew found a near overcast condition with cloud bases at about 3500 m. This altostratus deck was variable in density and coverage through the data period and was higher over the west end of the track, that is about 4 km. Cumulus began forming about the time of the start of data collection, increasing to two-eighths coverage by 1230 GMT and then remaining variable during the remainder of the data period. During the first ascent, a sharp haze discontinuity was noted at 1800 m marking the top of the surface-based haze layer. Within the layer, visibility was estimated at 20 km. Above 1800 m distinct multiple haze layers were identifiable but difficult to place at an accurate altitude. A secondary distinct haze top was identifiable at 2900 m. These conditions persisted through the data period. Surface observations at Rennes, 10 km north of the track, indicated variable cloudiness with better than 12-km visibility, a maximum temperature of 29°C, and easterly to southeasterly winds at 6 knots.

Aerosol Data Comments

Due to variability of the location of the flight path on this day (moving to avoid clouds, etc.), aerosol data at a given altitude may differ significantly. All data were taken in clear air, free of cloud influences.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 6 July 1977

Time Period of Flight: 0808-1156 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0915	150	60	41.21	70-80	-3.74
0905	460	180	36.12	70-80	-3.48
0925	1680	240	30.37	60-80	-3.18
0949	2880	191	15.65	55-65	-2.14

Second Data Set

1016	160	60	42.99	70-80	-3.66
1001	300	60	47.89	45-55	-4.28
1008	460	240	43.47	70-80	-3.28
1033	1680	240	29.63	60-80	-3.33
1058	2880	240	17.16	55-65	-2.30

Synoptic Weather Summary

The 500-mb height analysis continued to reflect a weak height field over all of western Europe. A weak trough was over the Bay of Biscay with a col dominating much of France. The surface map reflects similar weak synoptic features with a weak stationary system analyzed crossing France on a northwest-southeast line. The northwest portions were weak and well defined. The major feature was the moderately active frontal system entering the Bay of Biscay and slowly approaching the French coast.

Air Mass Summary

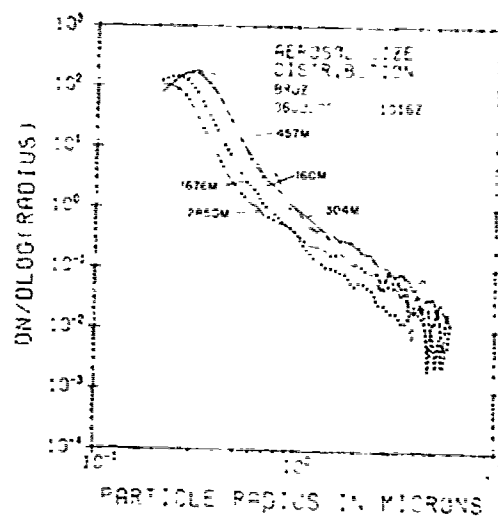
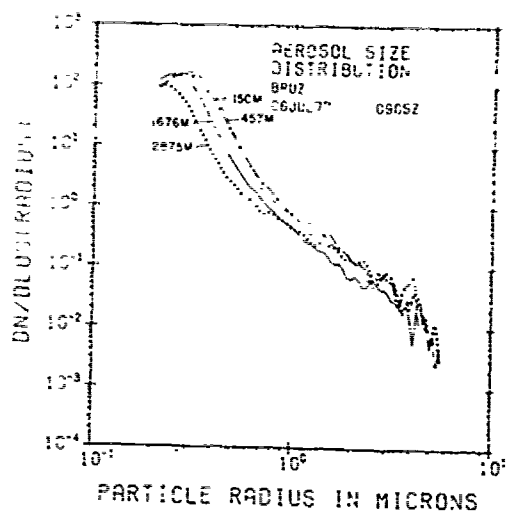
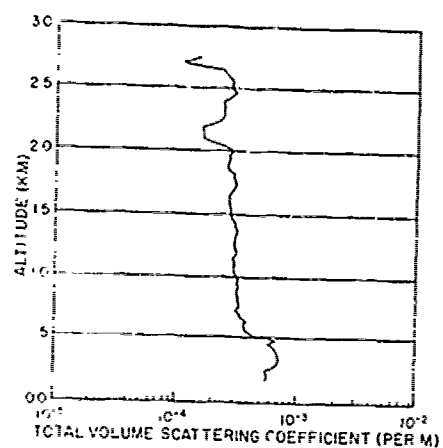
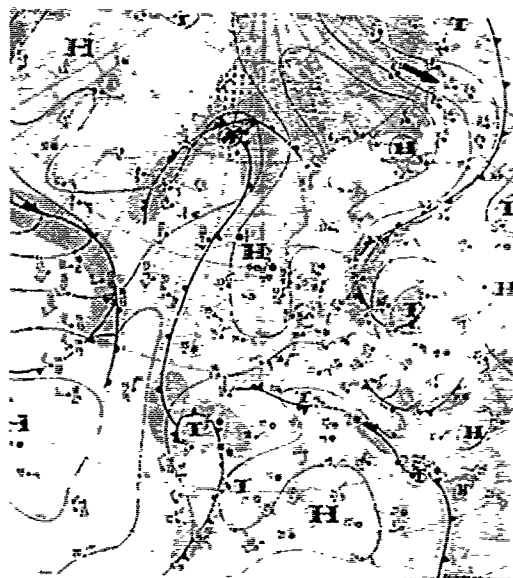
The dominant air mass continues to be maritime air recirculated over the continent from the northeast. With such a long residence time over land, the air mass characteristics are weakly maritime with strong continental influences. Dry surface conditions and high temperatures indicate a deep planetary boundary layer with significant haze densities.

Flight Summary

Upon arrival in the track area, the aircrew found conditions to be clear over the track but with a significant altocumulus deck (base 3100 m) to the west. Haze was found to be dense from the surface to 2300 m where a clear layer was observed extending to 2500 m; more dense haze was observed above 2500 m. At 2880 m the top of the haze appeared to be about 300 m above. During the first 150- and 460-m runs, conditions were clear, but broken altocumulus moving slowly southwest to northeast caused the remaining runs to be completed under cloud coverage. During the data period, Rennes, 10 km north of the track, reported visibility limited to 5 km and light northerly to northeasterly winds.

Aerosol Data Comments

All data were taken in clear air, free of cloud influences.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Bruz - 7 July 1977

Time Period of Flight: 0809-1310 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0850	410	240	44.12	70-75	-3.92
0920	1630	240	28.95	60-70	-3.28
0946	2850	240	2.59	40-60	-1.82
1014	5640	240	0.26	30-40	-1.88

Second Data Set

1059	150	60	44.70	50-60	-3.90
1049	250	225	46.83	70-80	-4.20
1123	1630	60	25.06	60-70	-3.44
1144	2850	60	5.60	35-40	-1.85
1217	5640	240	0.28	30-35	-2.39

Synoptic Weather Summary

Upper level charts show a weak trough over Spain, with a continuing weak height field at 500 mb over the remainder of western Europe. An associated surface low-pressure center is shown on the surface chart as it slid inland over southern France. A moderate pressure gradient existed over northern France creating a well-defined northeasterly flow at most levels below 6 km. Synoptic conditions were stable at 0000 GMT on 7 July and suggest only slowly changing conditions in the Bruz track area.

Air Mass Summary

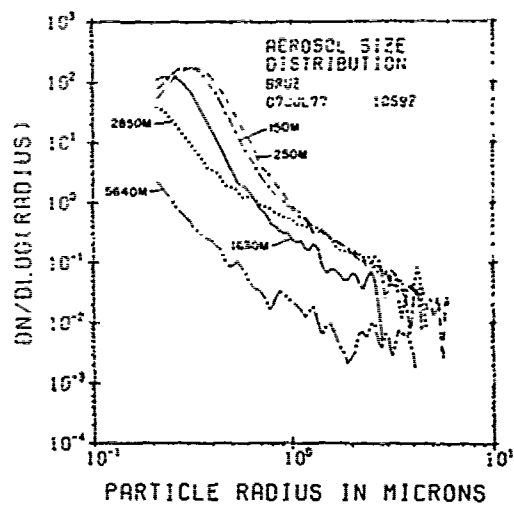
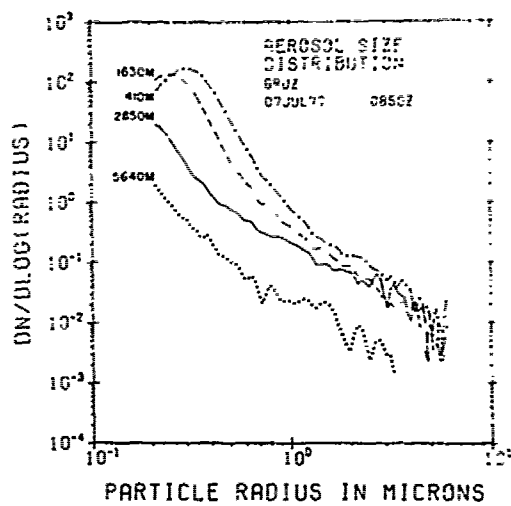
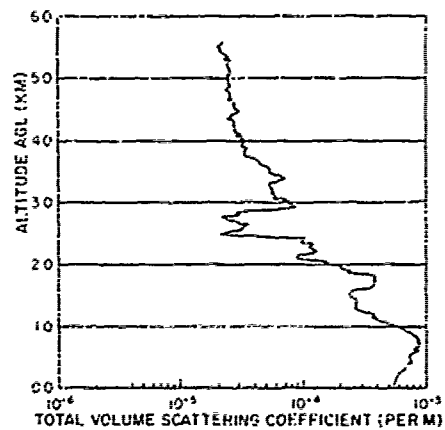
The dominant air mass is basically a continental air mass formed from long residence of maritime air over continental regions. High surface temperatures suggest a deeply mixed planetary boundary layer with significant haze densities.

Flight Summary

This was an excellent flight day with nearly clear skies during the entire data period. A vertical wall of clouds was observed about 30 km to the south; a feature that persisted all day. Only scattered cumulus along the data track occurred late in the day. Initially, haze was observed to be dense with an estimated visibility of 8 km. The top of the surface-based haze layer was observed to be at about 2000 m with another thin layer at 2850 to 3100 m. During the data period, observations at Rennes, 10 km north of the track, indicated 6-km visibility and northerly winds at 10 to 15 knots.

Aerosol Data Comments

None.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 29 July 1977

Time Period of Flight: 0944-1250 GMT Type of Data Flight: Dual 2+2

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1122	150	60	30.79	60-70	-5.34
1055	280	240	34.71	60-70	-4.24
1105	870	146	29.84	60-70	-3.96

Second Data Set

1136	150	60	39.84	60-70	-5.82
1133	280	240	30.69	60-70	-4.69
1158	870	240	32.23	60-70	-3.64

Synoptic Weather Summary

The 500-mb height chart shows a long wave trough line from Spitzbergen to Oslo, Belgium, and southwest France, with a northeast-southwest ridge from the Faeroe Islands to the mid-Atlantic. At the surface, a correlating trough dominated all of central Europe with a ridge of high pressure extending from the mid-Atlantic to Scotland and across the North Sea. The Meppen track area was pinched between the axes of the trough and ridge with moderate to weak northeasterly flow below 4500 m giving way to weak southwesterly flow aloft ahead of the approaching trough. Weather in the track area was dominated by unsettled conditions and extensive cloudiness in conjunction with the well-defined trough extending from the surface to 500-mb level.

Air Mass Summary

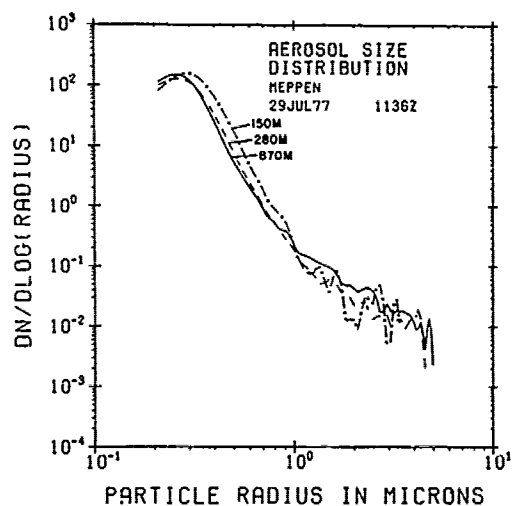
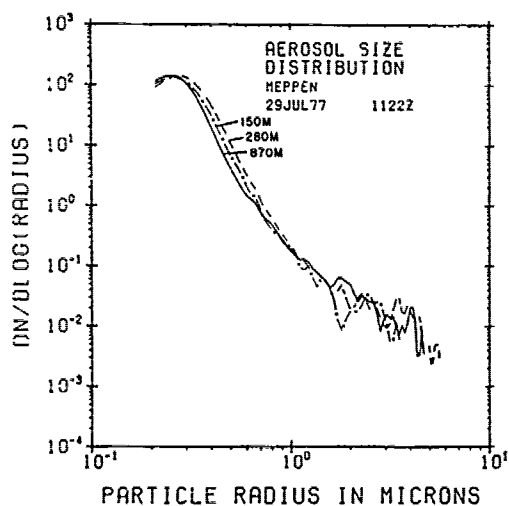
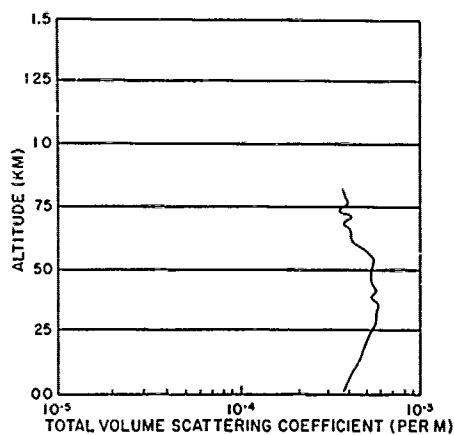
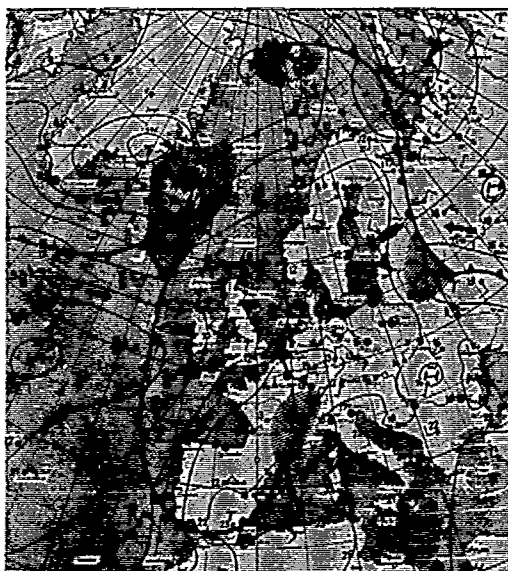
The air mass over Meppen was basically maritime; the air at low levels probably swept north of Great Britain over parts of Scandinavia into northern Germany. At higher levels, the air still had a maritime history, but from the North Atlantic to Spain and northeastward over the continent; the air may have been modified by continental influences. Widespread precipitation may have acted as a cleanser in the previous 24 hours.

Flight Summary

Weather conditions were terrible, limiting the flight to low altitudes. A consistent ceiling at 1700 m persisted through the data period with light rain. Very little rain was reaching the ground, with relative humidities of 60 to 70 percent up to 900 m; rain at 870 m was much harder than at 150 m. Haze was moderately dense and variable in the horizontal, with visibilities of near 30 km observed alternately with visibilities of 10 km. Isolated patches of stratus fractus at 600 m added to the day's miseries. During the data period, the area-meteorological observations indicated increasing clouds, lowering ceilings, occasional light rain, visibilities of 7 to 10 km, and northeasterly winds at 7 to 11 knots.

Aerosol Data Comments

Effects of precipitation on aerosol counts is unknown. Number densities appear realistic with what was observed visually. With uniform vertical mixing below clouds, little change in vertical would be expected. Observed variability in horizontal would be lost in longer samples and more apparent in shorter samples. Visibilities reported tend to support the measured concentrations.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 1 August 1977

Time Period of Flight: 1015-1540 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1209	180	60	19.41	50-60	-4.57
1208	280	240	18.31	55-60	-4.04
1219	1500	240	9.73	40-45	-5.08
1238	3060	240	2.63	45-50	-3.44
1248	4590	240	0.44	40-45	-2.37

Second Data Set

1312	180	60	11.91	50-60	-4.55
1327	280	240	9.83	55-60	-3.43
1353	1500	92	6.69	40-45	-4.57
1423	3060	60	2.68	45-50	-6.57

Synoptic Weather Summary

Upper level charts show a deep, slow moving trough over Scandinavia and Germany at 0000 GMT 1 August. The surface chart reflects this deep trough with a slowly eastward drifting region of low pressure over Poland. Despite the weak low west of Bergen, Norway, significant ridging from the Atlantic high-pressure center was developing over Great Britain, the North Sea, and Denmark. Conditions were stabilizing with a moderate flow around the maritime ridge.

Air Mass Summary

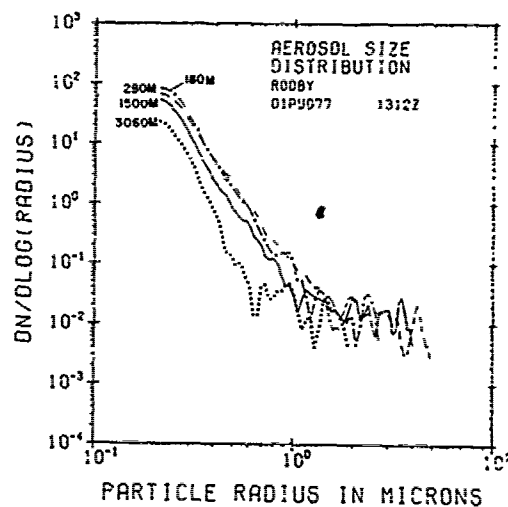
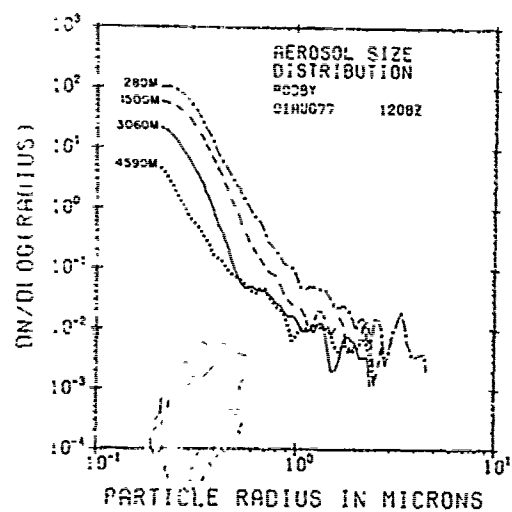
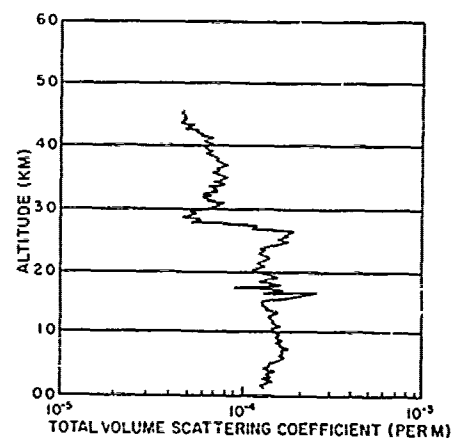
The dominant air mass was maritime polar, but with increasing ridging, vertical mixing was being suppressed. General flow in the track area was slow northeasterly, allowing a significant residence time of the maritime air mass over parts of Scandinavia.

Flight Summary

Overall, this was a beautiful day with only scattered cumulus and cirrus clouds. Cumulus clouds were forming over land areas and dissipating over water as they drifted off shore. Haze density was significant, with visibility initially limited to 25 km downsun and 5 km upsun at low altitude; it increased through the day to better than 50 km by the end of the data period. Initially, the surface-based haze top was observed to be about 1500 m, with well-marked multiple haze layers aloft. The highest haze layer was observed at 4500 m. During the data period, the lowest haze layer was compressed to 1200 m, but multiple layered haze remained, though less dense than at the start. During the data period, Fehmarnbelt Light Ship, 10 km south of the track, reported scattered clouds, 20-km visibility, and northerly winds at 15 knots.

Aerosol Data Comments

Significant changes occurred in the air mass haze characteristics during the data period. Haze layers aloft were observed to have considerable slope, such that some data runs literally traversed the depths of layers though in level flight. The most identifiable change was that the second set of measurements were taken in significantly thinner haze at low altitudes than the first set. Higher altitude changes were less distinct, as might be expected. The second data run at 4590 m was not made due to fuel limitations.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 4 August 1977

Time Period of Flight: 0755-1050 GMT Type of Data Flight: V-PRO

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0925	180	40	45.82	70	-6.27
0923	450	101	42.90	70	-6.23
0915	910	240	39.44	70	-4.68

Synoptic Weather Summary

The surface chart for 0000 GMT, 4 August, shows a weak cold front over Norway with its southernmost influences just reaching the North German coast. A second, more active storm system was located over Ireland, moving east, but was too far away to be an influence in the Meppen area. The pressure pattern over the continent was weak with very light northwesterly surface winds over northern Germany. The 500-mb chart likewise shows a weak height field over Europe, but with a deep closed low near Iceland. Winds over the UK were westerly, swinging southwesterly over the North Sea and southerly over Scandinavia. Little is depicted as changing in the Meppen area.

Air Mass Summary

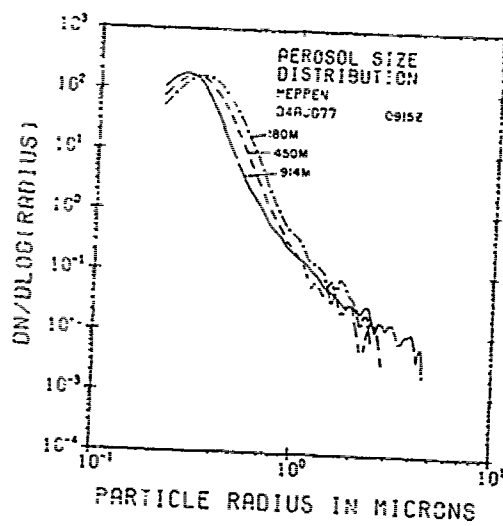
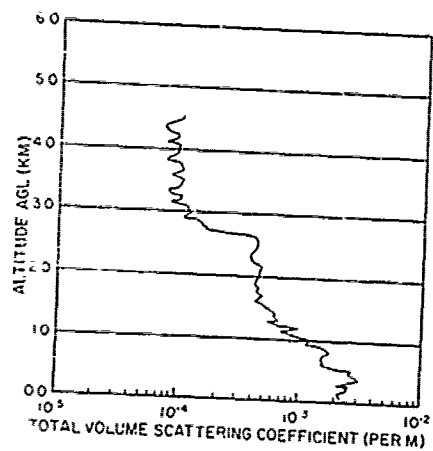
The air mass over Meppen on 4 August was circulating over continental regions for the previous week, with no significant influx of fresh maritime air. This air mass was, in its origin, maritime; with a long residence time over the continent, it should reflect strong continental influences. The morning sounding indicated the air mass was deeply mixed, very moist, and very unstable.

Flight Summary

Upon arrival in the Meppen track area, the aircrew found extensive cumulus cloud development. Haze was found to be extremely dense to great depth. Visibility was estimated at less than 3 km. The extreme haze density made a measurement effort highly desirable, but straight and level flight segments were not possible except below cloud base at 700 m. Consequently, a series of vertical profiles was flown between the Ahlhorn and Hopstein TACANS, 20 to 50 km south of the track. During the data period, the Ahlhorn weather observations indicated scattered to broken cloud coverage at 600 m, 3-km visibility, 20°C/15°C temperature/dewpoint, and winds variable out of the west at 3 to 6 knots.

Aerosol Data Comments

Aerosol measurements were made only at low altitude due to instrument flight conditions preventing short level-off periods other than in the Ahlhorn Radar Approach Control area. Data taken at 200 m during reconnaissance of the Meppen track show great similarity to these data.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 4 August 1977

Time Period of Flight: 1400-1605 GMT Type of Data Flight: Dual 2+2

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm^{-3})	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1518	180	60	37.10	40	-5.91
1535	260	240	36.86	40-45	-4.69
1444	750	240	38.37	60	-4.86

Second Data Set

1607	180	60	38.51	40	-5.77
1610	260	60	38.50	45	-5.45
1554	750	240	37.75	45-60	-4.54

Synoptic Weather Summary

During the day, the low-pressure center over Ireland at 0000 GMT, 4 August, (see previous mission surface chart) continued its east-northeast track. Pressure gradients over northern Germany strengthened only slightly as the frontal system approached. In response to weak ridging ahead of the front, winds over northern Germany strengthened slightly during the afternoon out of the northwest and north. Correspondingly, synoptic conditions stabilized during the afternoon in the pre-frontal environment, resulting in a dramatic decrease in cloudiness and humidity from the morning mission. Since the 0000 GMT surface chart for 4 August is shown with the previous mission, the 0000 GMT 500-mb chart is presented here for reference.

Air Mass Summary

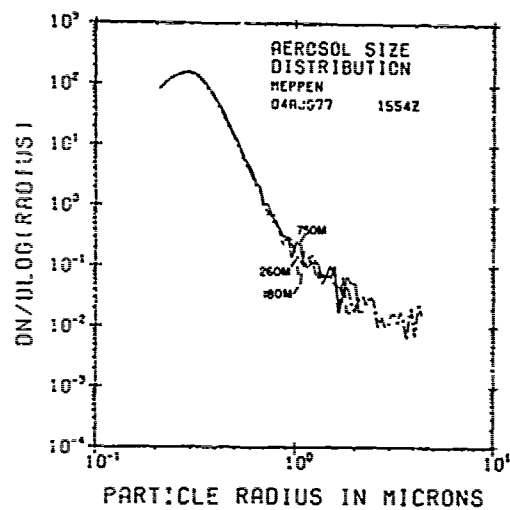
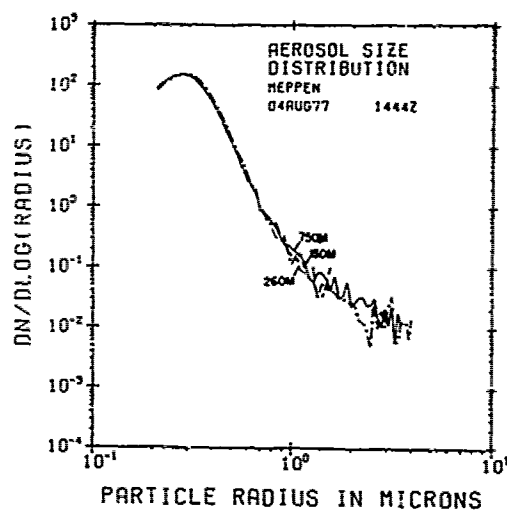
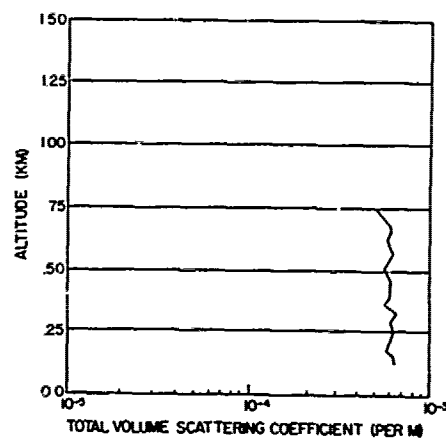
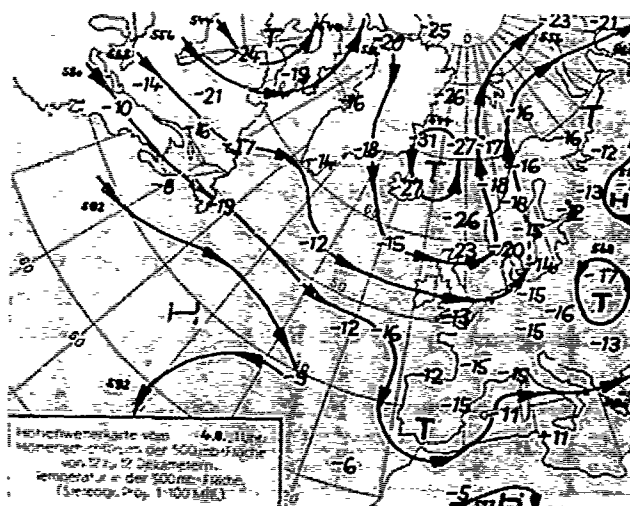
No significant change of air mass occurred between the two flights; thus the air mass over northern Germany remained maritime with a very strong continental influence in near stagnation conditions. Prefrontal ridging, however, created dramatic differences in the two periods; whereas the morning had high relative humidities (dewpoint depression 5°C), the afternoon was drier (dewpoint depression 8°C); whereas the morning was unstable and deeply mixed, the afternoon was much more stable and stratified.

Flight Summary

Upon arrival in the track area, the aircrew found the cumulus cloud cover to be in its dissipating stages. Cumulus bases were about 1000 m with moderate haze below. Visibility was estimated at 10 km or better, with uniform haze distributions in the vertical. The top of the surface-based haze was 1800 m. The Ahlhorn observation, basically for comparison to the morning meteo data, showed scattered cumulus, 6- to 10-km visibility, temperature 23°C , dewpoint 11°C , and winds northwest at 7 knots.

Aerosol Data Comments

It is apparent that a significant change was underway during this day. The morning flight was conducted in an unstable, high humidity air mass, while the afternoon flight took place under stabilizing conditions. There was no basic change of air mass, so the aerosol distributions show changes basically correlated to the change in relative humidity, that is, large enough for detection when wet, but not large enough when dry.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Meppen - 5 August 1977

Time Period of Flight: 0800-1247 GMT Type of Data Flight: Dual 2+3

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
0854	150	60	21.79	35-40	-3.82
0844	280	240	30.37	40-50	-4.04
0947	3060	240	0.05	55-60	-4.46

Second Data Set

0958	120	60	26.94	40	-4.04
1012	280	41	28.15	45	-3.96
1034	1041	240	11.24	40-50	-3.29
1104	3060	240	0.12	55-60	-2.92

Synoptic Weather Pattern

The surface analysis shows a weak surface pressure gradient over continental Europe at 0000 GMT. However, an active low pressure system was located between Scotland and Norway. A double frontal system was analyzed with an older, weaker leading front which extended to London, England, and a much more well-defined second front which extended on a line from Scotland to Ireland. The 500-mb analysis shows a very deep trough on a line along 10°W with a deep closed low over Iceland. Upper level flow over the North Sea was southwesterly, swinging southerly over Scandinavia. Flow over Meppen is light southwesterly. In this environment the closed surface low will track northeast with the trailing cold front slowly penetrating to the southeast towards the north German coast.

Air Mass Summary

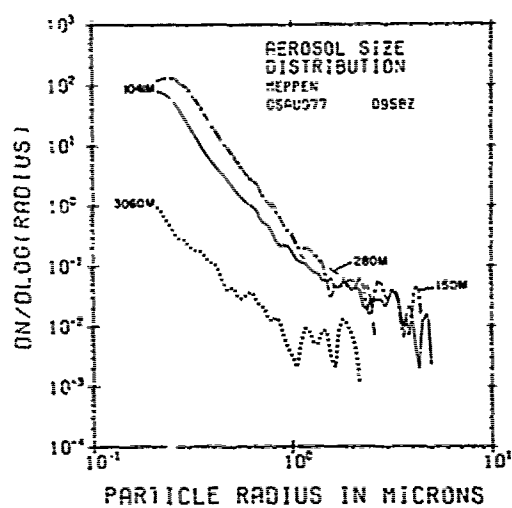
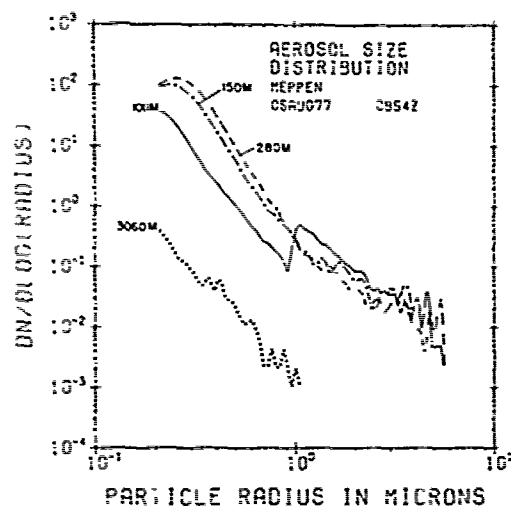
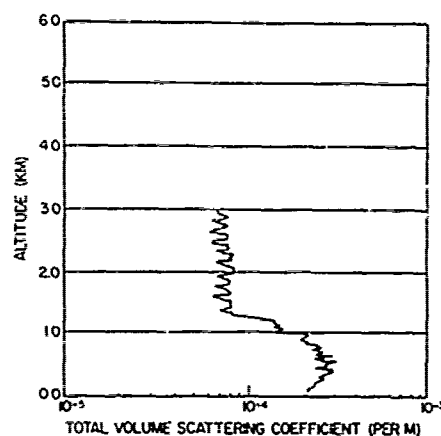
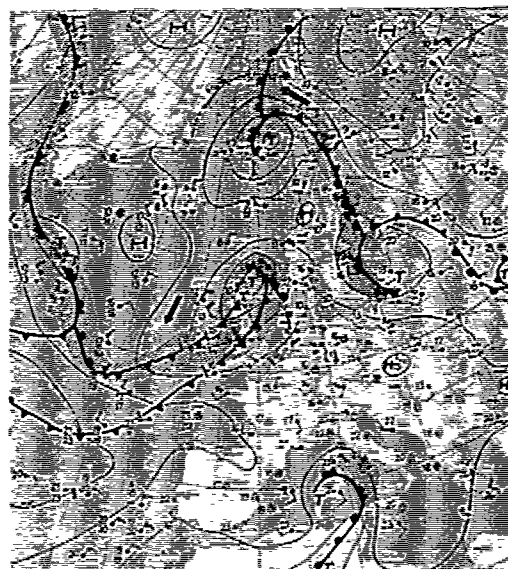
The air mass characteristics over Meppen started changing on 4 August from a fresher maritime air mass with northwest flow to maritime air with a long trajectory over land before reaching northern Germany from the southwest. On 5 August this southwesterly flow over northern Germany was well established ahead of the approaching front. This air mass, though maritime in history, possesses strong continental modifications.

Flight Summary

The data period for this flight was meteorologically persistent with scattered to broken thin cirrus above 5 km and light to moderate haze below 1200 m. Haze was nonuniform with much layered structuring. Only below 600 m did the haze begin to take on a resemblance of a vertically mixed layer. Later in the flight the depth of vertical mixing was observed to increase. Visibility in haze was estimated at 20 to 30 km. Surface reports in the track area indicate very similar conditions with visibilities from 12 to 30 km, 8°C dewpoint depressions, (drying) and southwesterly winds at 7 to 10 knots.

Aerosol Data Comments

None.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 10 August 1977

Time Period of Flight: 0930-1440 GMT Type of Data Flight: Dual 2+4

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for $r > 0.4 \mu\text{m}$
1024	120	44	11.82	70	-5.67
1025	490	240	18.26	55-60	-4.88
1034	1520	240	10.50	70-75	-5.46
1121	3390	240	1.31	55-60	-3.27
1139	5850	240	0.27	25-30	-4.19

Second Data Set

1210	120	60	17.44	65	-5.22
1221	280	55	15.50	65	-4.54
1258	1520	240	5.21	75	-5.04
1326	3390	240	0.64	50-55	-4.11
1353	5850	240	0.23	25-30	-4.44

Synoptic Weather Summary

The period for 4 days prior was marked by daily frontal passages over southern Scandinavia and much of northern Europe. On the surface map for 0000 GMT, 10 August, a dissipating occlusion is shown through the Rodby area, with a trailing front extending southwestward over Austria and northern Italy. Weak high pressure is shown dominating in the lee of the front as part of a ridge of high pressure extending along the Norwegian coast to London and the Azores. Upper level charts show a weak height field at 500-mb; low heights and cyclonic flow dominated all of Europe.

Air Mass Summary

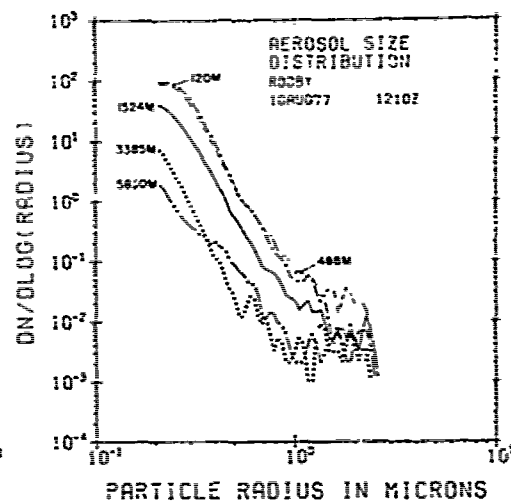
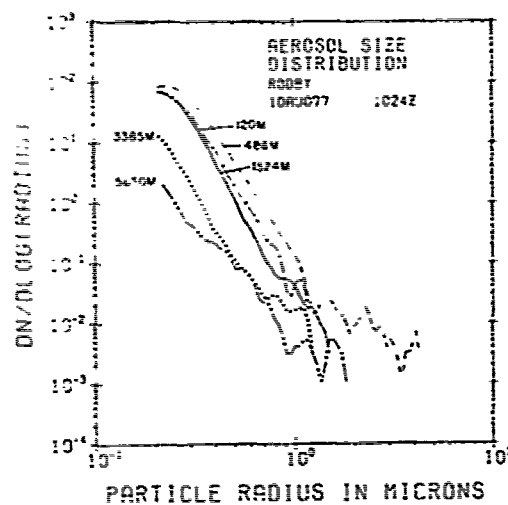
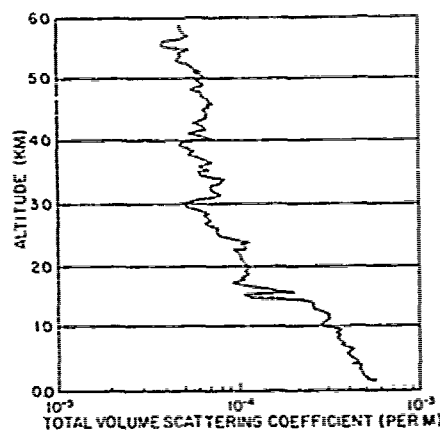
The dominant air mass was fresh maritime air, with a relatively short residence time over continental areas.

Flight Summary

Upon arrival in the track area the aircrew found scattered thin cirrus with cumulus starting to build over land areas to west and south. Haze was light with a highly layered structure from the surface to 5 km altitude. Initially, haze above 2000 m was thin, although sharply distinguishable against imbedded towering cumulus clouds which formed later in the data period. Cumulus coverage gradually increased while layering became more distinct with a well-defined surface layer topped at 1500 m. Only very thin layers were subsequently observable aloft. At Fehmarnbelt Lightship, 10 km south of track, the weather observer reported gradually increasing cloudiness through the period, 10 to 20 km visibility and highly variable light winds.

Aerosol Data Comments

The track area was in a period of change in the vertical structure and stability. The first data set at 1500 m was taken within the top of the surface based haze layer, while the second data set at 1500 m was in clear air above the surface layer upper boundary. A second, elevated, layer started at 2500 m during the second data set.



OPAQUE III
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Rodby - 11 August 1977

Time Period of Flight: 0920-1100 GMT Type of Data Flight: V-PRO

Significant Flight Data

First Data Set

Time (GMT)	Altitude (m)	Sample Length (sec)	Total Concentration (cm ⁻³)	Relative Humidity (%)	Slope for r > 0.4 μm
1012	120	60	31.32	60/Rain	-5.87
1010	280	240	29.10	55/Rain	-4.64
1028	1560	64	10.12	70/Rain	-4.93

Synoptic Weather Summary

The surface chart for 0000 GMT shows a broad, weak low-pressure influence over eastern Poland and the southern reaches of Scandinavia and the Baltic. High pressure is shown dominating the North Sea and very strong high pressure just east of Spitzbergen. The low pressure over eastern Europe was accompanied by widespread precipitation and historically appeared to be a stagnation of the system which had passed over Denmark 24 hours earlier. A look at the 500-mb chart reveals that an inverted block over Siberia retrogressed in the previous 24 hours, which caused the strongly cyclonic flow in its southwest quadrant to dominate southern Scandinavia. This was the root cause for the stagnation of the surface systems in eastern Europe, creating considerable cloudiness and weather in the Rodby track area.

Air Mass Summary

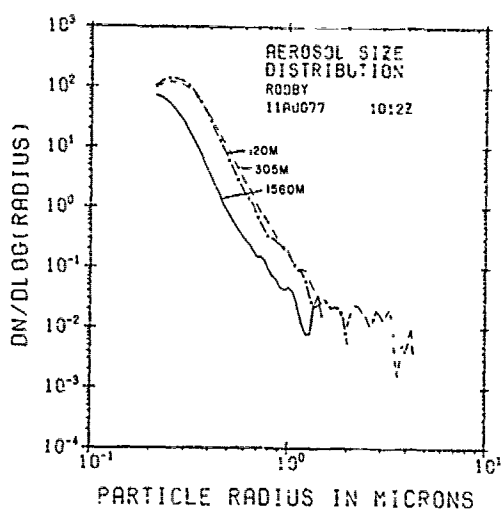
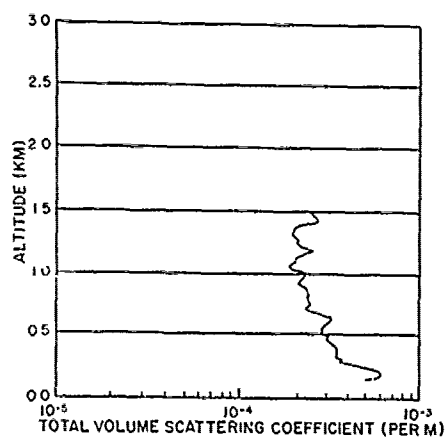
The dominant air mass over southern Denmark was maritime air which had been under near continental influences much longer than air on the previous day.

Flight Summary

A 2-km overcast and very light rain forced an abbreviated data mission. Haze was well-mixed from surface to cloud base, but haze density was nonuniform horizontally. Rain was generally light. Visibility was estimated at 8 km. Fehmarnbelt Lightship reported a continuous 300-m overcast, 6- to 10-km visibility and north-east winds at 8 knots.

Aerosol Data Comments

The net effect of the light rain on the aerosol data is unknown, but all indications are that the data are reliable. All data were taken free of clouds but within the precipitation area.



6. DATA DISCUSSION

It is not the intent of this discussion to present a thorough and comprehensive analysis of any facet of the data documented in the previous section. The purpose here is to present, in a highly abbreviated form, a series of comparisons, observations, and data characterizations accomplished during the data reduction and compilation. It is felt that presentation of these discussions here rather than in a later, more comprehensive, report gives the user of these data valuable insight into the comparability, representativeness, and reliability of the data base.

6.1 Aerosol Distribution versus Altitude

Aerosol measurements from an aircraft sampling platform using a method which draws a sample from the environment into the aircraft are subject to several potentially significant effects. The first is outright loss of particles to inlet orifices, tubing walls, and the like. Rigorously, this loss is an unknown, but design considerations in the C-130 sampling system minimized it. Due in part to effective design and the relatively narrow dynamic band sensitivity of the Royco counter, the shape of the distribution is presumed not to be significantly changed by preferential losses. Thus the relative shapes of the distributions are considered reliable, but the magnitude of the measured concentrations may, to a somewhat greater extent be more suspect.

As a cursory evaluation of the validity of the Royco data, a comparison was made of the distribution and concentration measurements against an existing altitude dependent data set. Figures 24 and 25, for 1.8- and 6.0-km altitude respectively, show the results of comparing the Royco data from Europe to Blifford and Ringer's¹⁷ impactor data from over the midwest of the United States. The curves from Blifford represent average $dN/d(\log R)$ [cm^{-3}] distributions calculated from a series of measurements in each season of the year. At 0.4-micron radius, considering all seasons, Blifford and Ringer found a variation from individual to individual measurement of about two orders of magnitude. At 2.0 microns, they found a tighter distribution variation (about one order of magnitude) between extreme values. The Royco data displays strong qualitative and quantitative agreement with the Blifford and Ringer data at nearly all sizes. The mild disagreement at small particle sizes falls in the range of increasingly small collection efficiencies of the impactor. The smoothness of the Royco data curves is due to the very high numbers of particles counted (typically thousands per data channel at lower altitudes) while the greater variation at sizes above 2.0-microns radius stems from lower particle counts and poorer statistical reliability.

17. Blifford, I.H., Jr. and Ringer, L.D. (1969) The size and number distribution of aerosols in the continental troposphere, J. Atmos. Sci. 26:716-726.

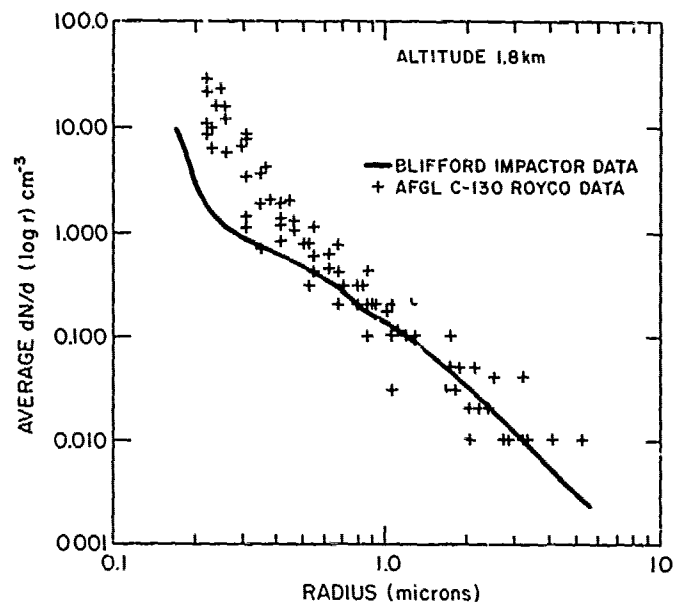


Figure 24. Aircraft Royco Data Taken at 1.8 km Altitude Compared to Mean Distributions at that Altitude Determined by Blifford and Ringer¹⁶ from a Series of Impactor Measurements

Blifford and Ringer¹⁷ found a strong suggestion of seasonal variations in the aerosol distributions, whereas the C-130 data suggest a much more consistent pattern through the seasons at both low and high altitudes. This may be a function of the strongly moderating maritime influence which tends to predominate over Europe in comparison to the midwestern United States.

Individual variations between Blifford's data and the C-130 Royco data do not, however, constitute the most significant fact: these two data sets, from different parts of the world, and taken by different techniques, favorably compare to one another. The suggestion is not lost that there may be in the atmosphere a very basic aerosol distribution relationship upon which local, meso- or synoptic-scale effects are superimposed.

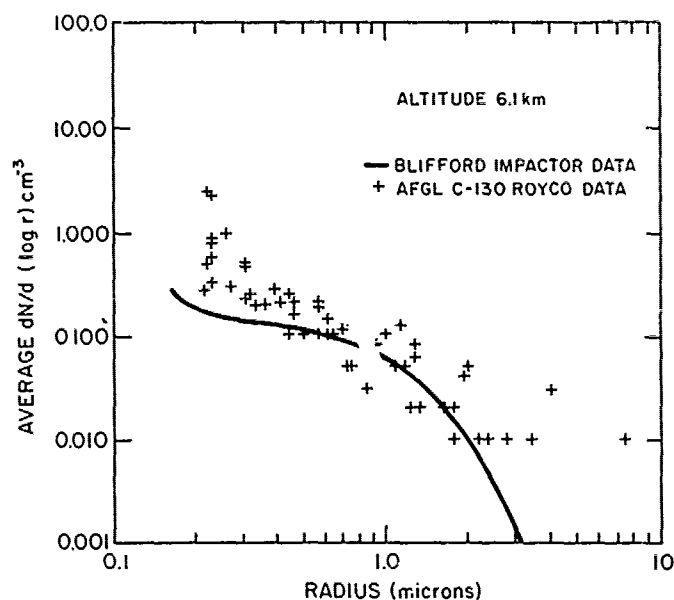


Figure 25. Aircraft Royco Data Taken at 6.0 km Altitude Compared to Mean Distribution at that Altitude Determined by Blifford and Ringer¹⁷

6.2 Junge Slope Characterization

The Junge Distribution, the slope of the distribution expressed as b in the equation

$$\frac{dN}{d(\log r)} = ar^b$$

is one of the most common methods of comparing aerosol measurements made in the free atmosphere. Typically, the value of b , the slope on a log-log plot, is -3 . Using the data presented in the prior section, stratified only by the season during which the data were collected, Figures 26 through 28 illustrate the observed character of the Junge slopes calculated. In the calculation, each data distribution is smoothed by a three-point running mean to minimize the effect of bin size irregularities in the pulse height analyzer, and to avoid isolated zero values in larger particle bins. The effect of this smoothing is negligible, considering the extreme narrowness of 100 bins spread over a range of about 13 micrometers.

The spring 1976 data show a consistency and lack of scatter missing in both the summer 1977 data and the fall 1976 data. The spring data were acquired by taking ten-minute samples as previously described, probably accounting for the

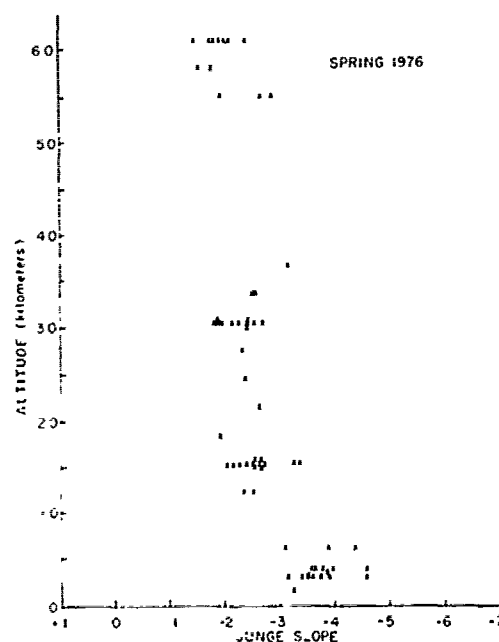


Figure 26. Vertical Variation of Jungge Slope Determined Using 10-Minute Sample Data During OPAQUE I (Spring 1976)

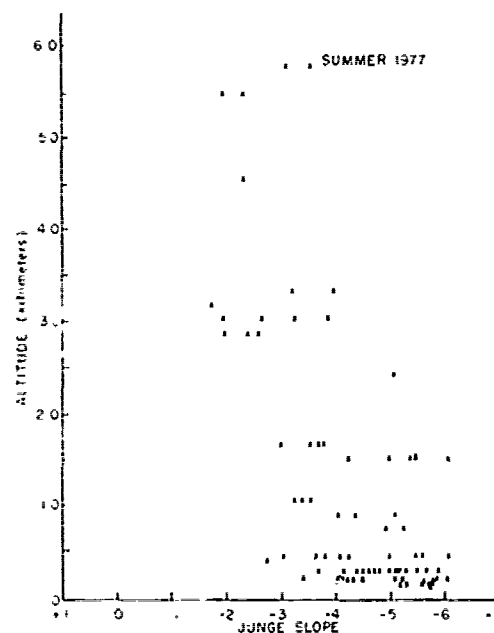


Figure 27. Vertical Variation of Jungge Slope Determined Using 1-, 4-, and 10-Minute Sample Data During OPAQUE III (Summer 1977)

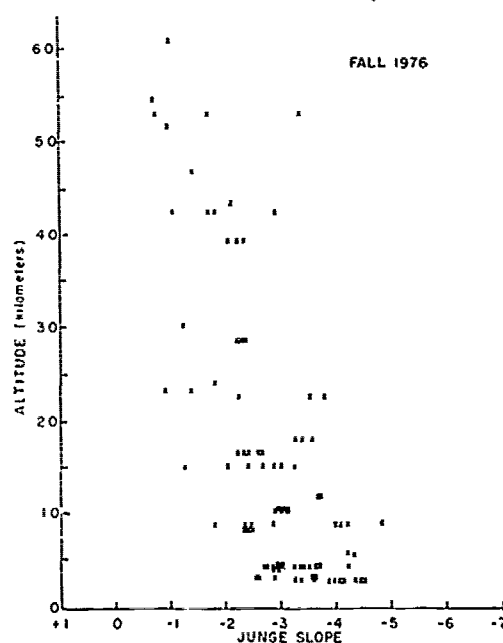


Figure 28. Vertical Variation of Jungge Slope Determined Using 1- and 4-Minute Sample Data During OPAQUE II (Fall 1976)

uniformity. Two major factors are readily apparent; within the planetary boundary layer (PBL) the Junge Slopes typically range from -3 to -4.5, and the Junge slopes decrease with height tending towards a value of -2, characteristic of all altitudes above the PBL.

In comparison, the summer 1977 data show significantly greater scatter at all altitudes, with the greatest variations occurring within the PBL. This is contrary to the findings of Hofmann, et al,¹⁸ who found that over a given site, the vertical aerosol structure was more consistent during the summer months than spring or fall. Figure 27 represents all samples acquired without sorting; sampling times are nonuniform with one, four and a few ten-minute samples; samples are non-uniformly distributed in time, that is a single value may come from one day and several values could be derived from several samples on the same day; and all geographical sites are included. The scatter both within and above the PBL is readily apparent, and could be easily attributed to the generally shorter (one- and four-minute) sampling times used during this period, but is also possibly representative of the wide variety of conditions encountered during the summer months in the different geographical areas and synoptic situations, ranging from hot, hazy, and stagnant to fresh, cool, and wet. The factors influencing the scatter are explored in greater refinement in the next section. Note that the scatter within the PBL ranges from -3 to -6 and that, as in the spring, the Junge distribution flattens with altitude tending towards -2 at the top of the PBL and above.

The fall 1976 data, presented in the same format and acquired with predominately four-minute samples, strongly supports the previous observations. Slopes of -2.5 to -5 are found within the PBL; they flatten with altitude tending to -2 at the top of the PBL and above. Perhaps significantly, there tends to be slightly greater consistency in the fall data, possibly reflecting a more stable environment or the absence of many one-minute samples.

Overall, slopes of -3 to -6 seem to be a systematic characteristic within the PBL, while the flattening towards a slope of -2 seems a very consistent result and may be an atmospheric characteristic.

6.3 Horizontal Homogeneity of Aerosol Distribution

Typically, aerosol measurements acquired during stable conditions and at the same altitude over short periods of time in the same approximate airspace were exceptionally consistent. A series of measurements acquired over a short period during more or less static conditions on 26 October 1976 near Rodby, Denmark, at 305-meters altitude, is illustrative (Figure 29a), as is the series of

18. Hoffman, D.J., Rosen, J.M., Pepin, T.J., and Pinnick, R.G. (1975) Stratospheric aerosol measurements: time variations at northern midlatitudes, J. Atmos. Sci. 32:1446-1456.

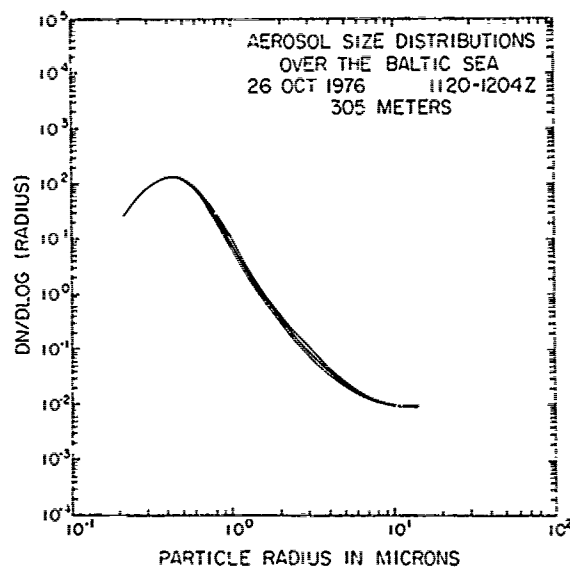


Figure 29a. Set of Three Aerosol Distributions Acquired Over the Period of 40 Minutes near Rodby, Denmark at an Altitude of 305 m

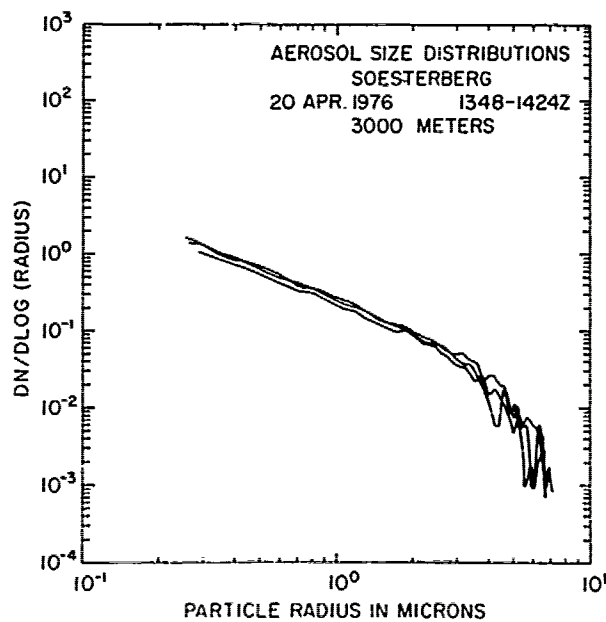


Figure 29b. Set of Three Aerosol Distributions Acquired Over a Period of 30 Minutes at 3 km Altitude Over the Netherlands on 20 April 1976

measurements from 3 km over the Netherlands on 20 April 1976 (Figure 29b). The consistency on these days extended to both the shape of the distribution and the measured concentrations. Examples are present in the data in Section 5, where either the distribution or the concentration changed significantly, but not necessarily both.

The frequent horizontal homogeneity observed can not, however, be generalized into an assumption about its probable presence. Figures 30 and 31 show similar data series from different dates and times. These indicate significant changes occurring at a given altitude, showing spatial and/or temporal variations in measurable aerosol character. In particular, Figure 30 shows the change which accompanied a weak frontal system moving across northwestern France. Figure 31, on the other hand, shows distributions measured on the ends of an altered Rodby track (north-south under 1000-m overcast). A short time later a second data series, Figure 32, indicates that the haze advected or developed to be approximately equally dense over the length of the track. On this day, horizontal homogeneity did not exist.

In these comparisons, instrument consistency is very important; and the conclusion from many such measurements was that the Royco measurements are reliably consistent and comparable. A question remains, however, about comparing aerosol distributions acquired with different (for example, one-minute and ten-minute) total accumulation (or integration) times. If the scale upon which fully mixed atmospheric aerosol content varies significantly is less than 5 km, the one- and ten-minute samples are directly comparable and should display the same degree of variation.* It is suggested by comparison of one- and ten-minute samples, however, that the ten-minute accumulation integrates through scale variations that are reflected in one-minute data samples. Figure 33 illustrates that comparison of the scatter about the mean (the standard deviation was used) for all one-, four-, and ten-minute samples (without regard to season) indicates that the same tendency towards a decreasing range of variability with increasing sample length exists at all altitudes. The stratification by altitude is significant in that within the PBL, a one-minute sample will contain several thousand particle counts and is nearly as statistically significant as the ten-minute sample. The tendency for one-minute samples in the PBL to display a significantly greater scatter about the mean suggests significant aerosol density variations over distances of 5 km. or less.* The consistency of this tendency from altitude to higher altitude indicates a like but smaller variability in the spatial aerosol distributions at altitudes above the PBL. At no altitude in this data set is there the indication of true horizontal

* One- and ten-minute sampling times correspond to 5 and 50 km, respectively.

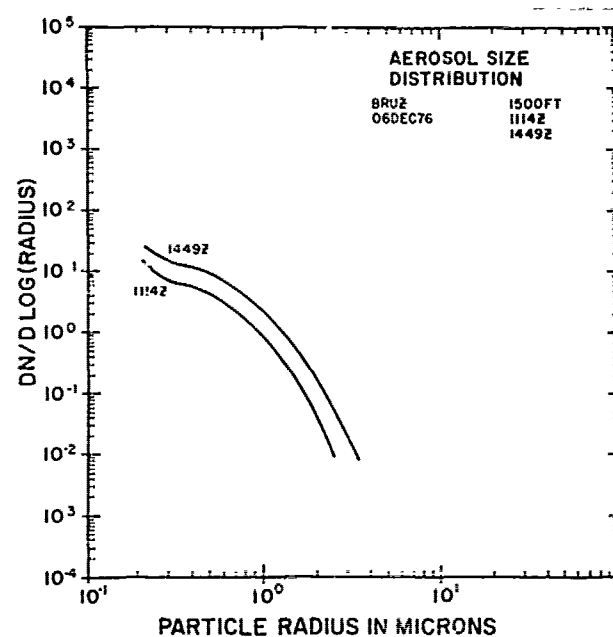


Figure 30. Two Aerosol Distributions Acquired Before and After a Weak Frontal Passage over Northwestern France on 6 December 1976 at an Altitude of 430 m

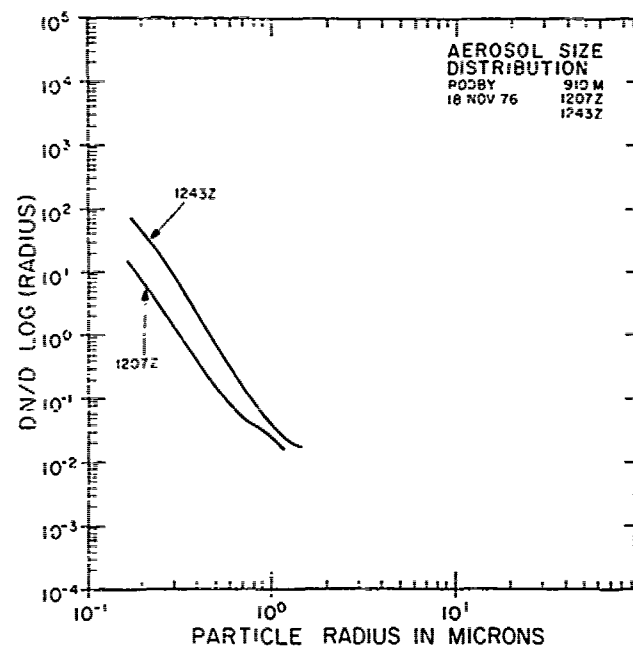


Figure 31. Aerosol Distributions Acquired at the Same Altitude, 410 m, near Rodby, Denmark on 18 November 1976, 50 km Apart in Observably Different Haze Densities

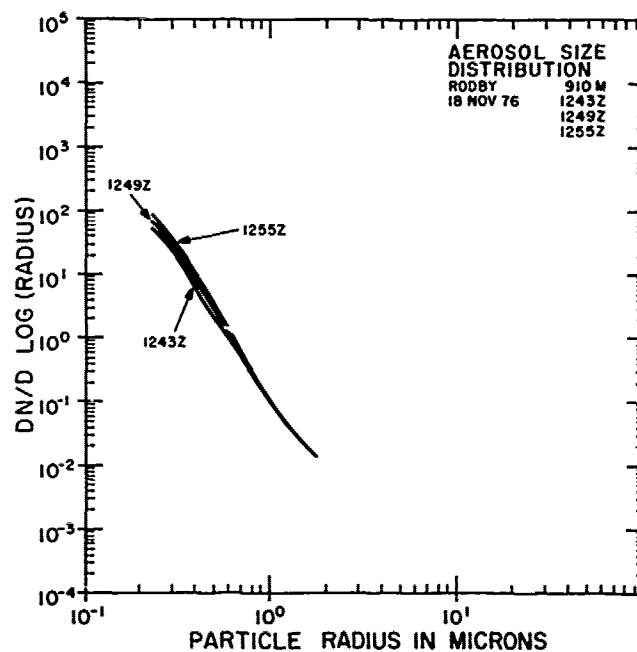


Figure 32. Aerosol Distributions Acquired at Same Altitude and Locations as Previous Figure but Showing the Spread and Consistency of the Denser Haze Conditions. Three data sets are approximately equally spaced along 50 km of track

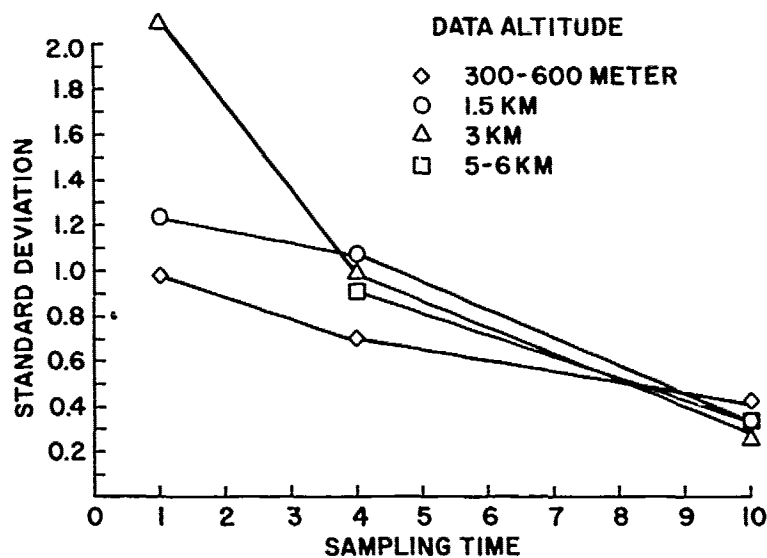


Figure 33. Standard Deviations of Junge Slopes for all 1-, 4-, and 10-Minute Data Samples Stratified by Altitude Ranges. Too few one-minute samples were taken at 6 km for consideration (four sample minute standard deviation was 1.16)

homogeneity, but the convergence of the ten-minute samples possibly indicates the existence of a spatially integrated homogeneity on some larger scale.

6.4 Extinction Calculations Using Aerosol Data

To investigate the absolute reliability of the aerosol measurements, a Mie scattering code was used to calculate the scattering to be expected from the measured aerosol distribution. The results of these calculations were compared to measurements of total scattering from the integrating nephelometer. Only data acquired in the same straight and level flight segment were used, but the two measurements were not necessarily simultaneous or of the same duration. As was indicated in previous sections, this lack of simultaneity should introduce substantially larger variabilities than if data were truly coincident.

Due to the relatively narrow limits of the Royco counter's size capability, and the potentially significant impact on the total aerosol scattering at 0.455 micrometers by particles less than 0.4 micrometers in size, the measured aerosol samples were extrapolated to represent a size distribution from 0.1 to about 120 micrometers. On the small end a log-normal distribution* was fit to the slope of the measured distribution over the first eight size bins, while for particles larger than 0.8 micrometers, the measured distribution was linearly extrapolated as shown in Figure 34. Typically, the distribution below 0.4 micrometers was found to add less than 15 percent to the total scattering, while the larger sizes were found to add less than 1 percent.

The results of these calculations and comparisons indicate that the calculated scattering is always less than the measured, but that the magnitude of its departure varies by factors of two to factors of 20 depending, apparently, on haze density. It was expected to find differences of two to five based on instrument performances during previously-mentioned test and evaluation efforts.

Based on "total scattering" (Mie + Rayleigh), Figure 35 indicates a potential correlation between the size of the ratio (measured scattering coefficient over that calculated from the aerosol distribution) and the total scattering. This correlation disappears in Figure 36, where Rayleigh scattering and its dominance at low aerosol concentrations is removed. However, if only those aerosol and nephelometer

* Log-normal distribution equation:

$$\frac{dN}{d \log r} = \frac{N_0}{6 \sqrt{2} \pi} \exp \left[- \frac{(\log r - \log r_0)^2}{2 r} \right]$$

The log normal size distribution is Gaussian in $\log r$. In fitting the measured data, the width 6 was held fixed; the mode radius r_0 and total number of particles in the first 8 size bins to the values for the log-normal distribution.

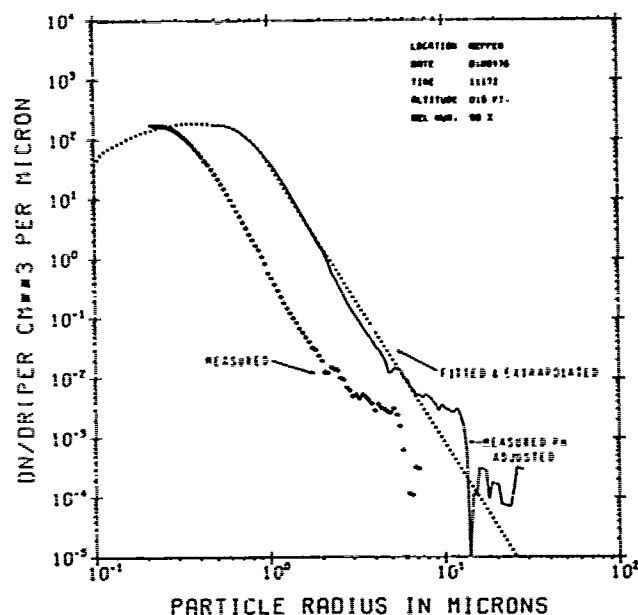


Figure 34. Airborne Aerosol Distribution Adjusted to Ambient Relative Humidity and Extrapolated for Mie Scattering Calculation at 0.455 Micrometers

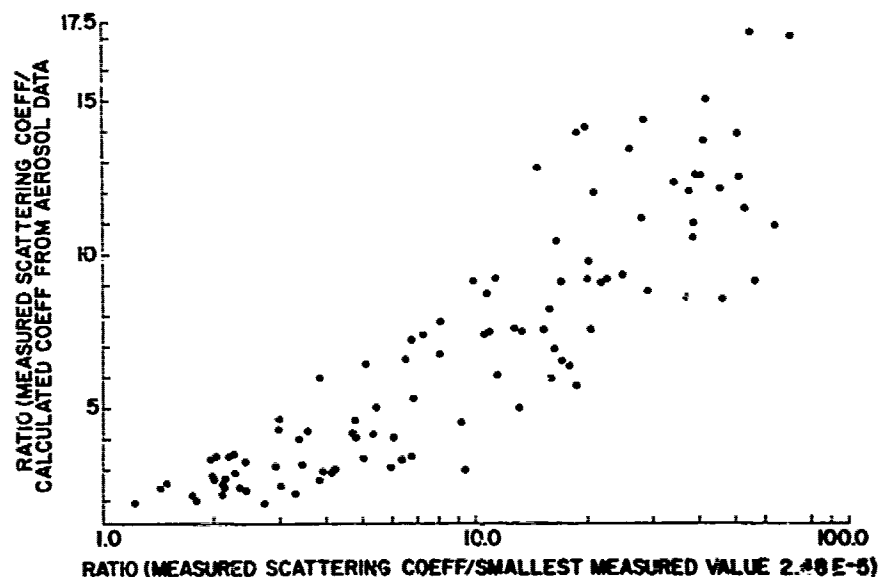


Figure 35. Comparison of Variability of the Ratio of the Measured Scattering Coefficient to the Scattering Coefficient Calculated from Actual Aerosol Distribution in Terms of the Range of Observed Haze Density (in Terms of the Ratio of Measured Scattering Coefficient Over the Minimum Observed Value of 3×10^{-5}). Scattering coefficients and aerosol distributions measured on same straight and level profile leg are used but are not necessarily simultaneous

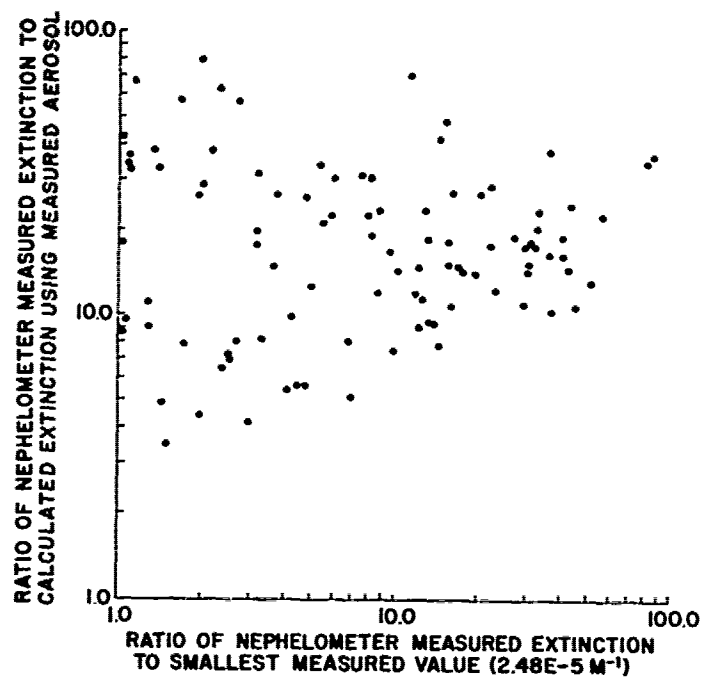


Figure 36. Same Comparison as Figure 35 with Rayleigh Component of Scattering Removed

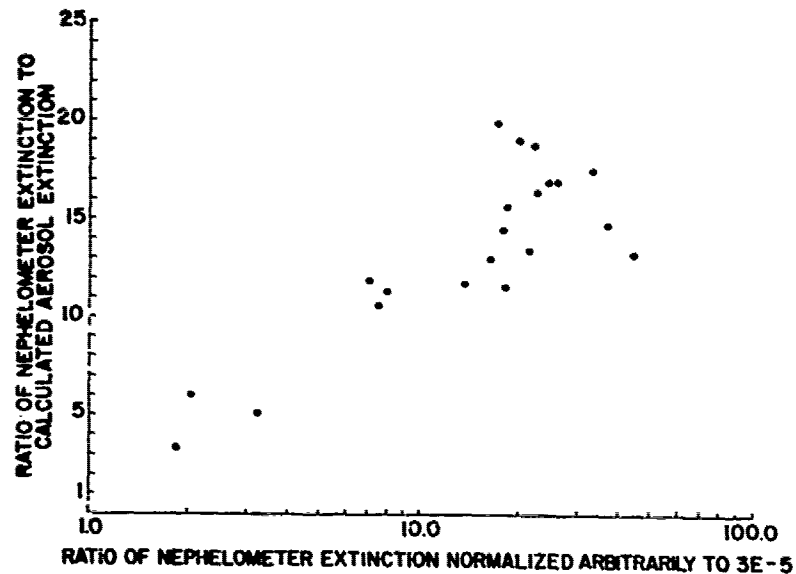


Figure 37. Same Comparison as Figure 36 Using Only Simultaneous Data

measurements which are truly simultaneous are used, order reappears (Figure 37), and again a strong suggestion of increasing losses of particles with increasing haze density exists. The differences between measured and calculated run from two to 20 over an order of magnitude change in the mie scattering extinction.

If it is assumed the aerosol sample being drawn into the Royco counter is "dried" in the warm plumbing, and not at all in the nephelometer, then accounting for relative humidity should account for much of the disagreement shown in Figure 37. Growing the "dry" measured distribution to the ambient measured relative humidity was done following procedures of Shettle and Fenn,¹⁹ based on Hänel's²⁰ data. When introduced into the Mie scattering code, the now "wet" distributions place about two-thirds of the points in Figure 37 to within a ratio of two to five range on the ordinate scale; about what was expected.

Though not conclusive, it does not seem unreasonable to conclude that wet atmospheric particles are substantially dried before being sized and counted. It is perhaps best, then, to consider size distributions presented in this report as reflecting the shape of the "dry" aerosol distribution, rather than what the nephelometer actually sees. The number concentrations are probably consistently low by at least a factor of two.

7. SUMMARY AND CONCLUSIONS

Although the aerosol distribution curves are shown not to be correct with respect to total concentration, it is felt that the shapes of the distributions and the tendencies identifiable are reliable. The concentration measurements are consistently factors of two to five low in comparison to the nephelometer measurements, and are as low as a factor of ten to 20 in some cases. It is probable that these aerosol measurements represent the dry particle distribution (that is, low relative humidity), and that to be used properly, relative humidity effects must be incorporated.

In relative terms, the spatial variations in both the horizontal and vertical seem very consistent and reliable. In the horizontal, spatial variations on the order of several kilometers are strongly indicated by variations in both concentration and distribution. These variations are apparently quite consistent in time and/or space, since distributions taken with longer sampling times tend to

19. Shettle, E. P. and Fenn, R. V. (1979) Models For the Aerosol of the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties, AFGL-TR-79-0214, AD A085 951.

20. Hänel, G. (1976) The properties of atmospheric aerosol particles as functions of the relative humidity at thermodynamic equilibrium with the surrounding moist air, Advances in Geophysics 19:73-188.

converge, greatly reducing the scatter of data points. Variations found in shorter sampling time data are most marked in the PBL, where confidence in the measurements is high, and are likewise found in the more homogeneous layers above the PBL.

Junge slopes were used to compare and characterize stratified groups of aerosol data sets. In the PBL, Junge slopes were found to vary from -3 to -6, while at higher altitudes the slopes tend to flatten towards -2 at the top of the PBL and remain approximately unchanged up to 6-km altitude. This indication of a preferential loss of smaller particles is not to be unexpected if it is argued that the primary "stocking" mechanism for aerosol populations from the top of the PBL to 6.0 km is cloud "pumping," that is, clouds acting as the mechanism by which low-altitude aerosol particles are run through the wet cloud processing and pumped to higher altitude. In so doing, assuming an obviously simplistic approach, large particle collection will be dominate, resulting in a gross loss of the small end of the size spectrum—exactly what appears to be seen.

It should be noted, however, that the Junge slope characterization of these data sets is crude at best. The distributions are just not that simple. It is seen, however, as a convenient medium for comparison of general tendencies.

This aerosol data set is considered a valuable and reliable vehicle to further understanding of the vertical variation of free atmosphere aerosol distributions. Constraints do exist in the data set and these are discussed and pointed out. As is usually the case, these distributions must be used with a bit of caution and a lot of common sense.

References

1. Fenn, R.W. (1978) OPAQUE--A Measurement Program on Optical Atmospheric Quantities in Europe, Volume II--The NATO OPAQUE Program, AFGL-TR-78-0011, ADB029877L. (Distribution limited to U.S. Government Agencies only.)
2. Fenn, R.W. et al (1979) OPAQUE--A Measurement Program on Optical Atmospheric Quantities in Europe, Volume II--The US/German OPAQUE Station Near Meppen, FRG, AFGL-TR-78-0068, AD B045 111L, (Distribution limited to U.S. Government Agencies only).
3. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1976) Airborne Measurements of Optical Atmospheric Properties in Northern Germany, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 76-17, AFCRL-TR-76-0188, AD A035 571.
4. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1972) Airborne Measurements of Optical Atmospheric Properties in Southern Germany, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 72-64, AFCRL-72-0255, AD 747 490.
5. Duntley, S.Q., Johnson, R.W., Gordone, J.I., and Boileau, A.R. (1970) Airborne Measurements of Optical Atmospheric Properties at Night, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 70-7, AFCRL-70-0137, AD 870 734.
6. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1975) Airborne Measurements of Optical Properties, Summary and Review II, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 75-26, AFCRL-TR-75-0457, AD A022 675.
7. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1978c) Airborne Measurements of Optical Properties, Summary and Review III, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 79-5, AFCRL-TR-78-0286, AD A073 121.
8. Zinky, W.R. (1962) A new tool for air pollution control: The aerosol particle Counter, J. Air Pollution Control Assoc. 12:578.

9. Cooke, D.D. and Kerker, M. (1975) Response calculations for light-scattering aerosol particle counters, Applied Optics 14(No. 3):734-739.
10. Quenzel, H. (1969) Influence of refractive index on the accuracy of size determination of aerosol particles with light scattering aerosol counters, Applied Optics 8(No. 1):165-169.
11. Michaels, S.C. and D'Acierno, J.P. (1976) Evaluation of Aerosol Generation and Counting Techniques, ORNL/MIT-228, 24 March 1976.
12. Cress, T.S. and Fenn, R.W. (1978) OPAQUE Aerosol Counter Intercomparison 25 April 1977-4 May 1977, AFGL-TR-78-0004, AD B029 309.
13. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1977) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Spring 1976, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 77-8, AFGL-TR-77-0078, AD A046 290.
14. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1978a) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Summer 1977, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 78-28, AFGL-TR-78-0168, AD A068 611.
15. Duntley, S.Q., Johnson, R.W., and Gordon, J.I. (1978b) Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Fall 1976, University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref. 78-3, AFGL-TR-77-0239, AD A057 144.
16. Lahey, J.F., Bryson, R.A., Wahl, E.W., Horn, L.H., and Henderson, V.D. (1958) Atlas of 500 mb Wind Characteristics for the Northern Hemisphere, AFCRC-TN-57-602.
17. Blifford, I.H., Jr. and Ringer, L.D. (1969) The size and number distribution of aerosols in the continental troposphere, J. Atmos. Sci. 26:716-726.
18. Hoffman, D.J., Rosen, J.M., Pepin, T.J., and Pinnick, R.G. (1975) Stratospheric aerosol measurements: time variations at northern midlatitudes, J. Atmos. Sci. 32:1446-1456.
19. Shettle, E.P. and Fenn, R.W. (1979) Models For the Aerosol of the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties, AFGL-TR-79-0214, AD A085 951.
20. Hänel, G. (1976) The properties of atmospheric aerosol particles as functions of the relative humidity at thermodynamic equilibrium with the surrounding moist air, Advances in Geophysics 19:73-188.